MATH AND SCIENCE @ WORK

AP* CHEMISTRY Educator Edition

CARBON DIOXIDE REMOVAL – THERMODYNAMICS

Note: This problem is related to the chemistry problem *Carbon Dioxide Removal – Stoichiometry* and the biology problem *Respiration in Spaceflight* in the Math and Science @ Work series.

Instructional Objectives

Students will

- find standard enthalpy change, ΔH°_{rxn}, using Hess's Law;
- determine the standard entropy change, ΔS°, for a reaction;
- determine the standard free energy change, ΔG°, for a reaction;
- use the sign of ΔG° to predict the spontaneity of a reaction; and
- determine the equilibrium constant, K_{eq}, for a reaction.

Degree of Difficulty

These problems require 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 30-40 minutes.

- Introduction: 5 minutes
- Student Work Time: 15-20 minutes
- Post Discussion: 10-15 minutes

Background

This problem is part of a series of problems that apply Math and Science @ Work in NASA's Mission Control Center.

Since its conception in 1981, NASA has used the space shuttle for human transport, the construction of the International Space Station (ISS), and to research the effects of space on the human body. One of the keys to the success of the Space Shuttle Program is the Space Shuttle Mission Control Center (MCC). The Space Shuttle MCC at NASA Johnson Space Center uses some of the most sophisticated technology and communication equipment in the world to monitor and control the space shuttle flights.

Grade Level
11-12

Key Topic
Thermodynamics

Degree of Difficulty
Moderate

Teacher Prep Time
5-10 minutes

Class Time Required
30-40 minutes

Technology
Calculator

AP Course Topics
Reactions:
-Thermodynamics

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

Within the Space Shuttle MCC, teams of highly qualified engineers, scientists, doctors, and technicians, known as flight controllers, monitor the systems and activities aboard the space shuttle. They work together as a powerful team, spending many hours performing critical simulations as they prepare to support preflight, ascent, flight, and reentry of the space shuttle and the crew. The flight controllers provide the knowledge and expertise needed to support normal operations and any unexpected events.

One of the flight control positions in the Space Shuttle Mission Control Center is the Emergency, Environmental, and Consumables Manager (EECOM). One of the responsibilities of the EECOM flight controller is to monitor and regulate the cabin atmosphere which includes gas concentrations and pressures within the space shuttle cabin. Maintaining these parameters ensures a habitable cabin atmosphere and temperature on board the space shuttle much like the atmosphere here on Earth.

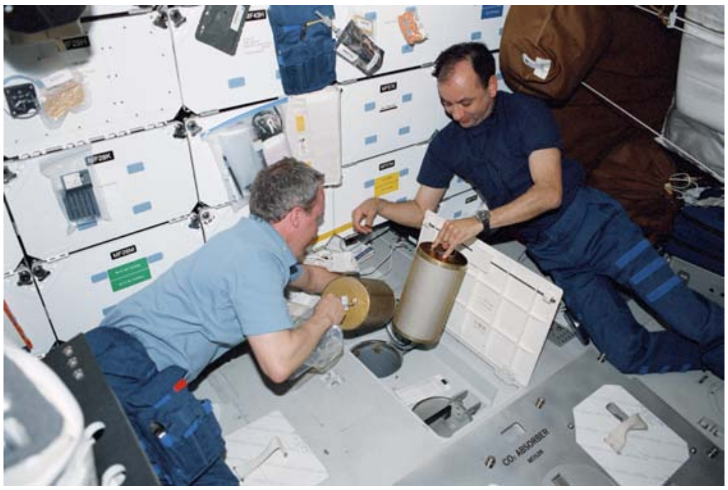

Figure 1: Astronauts Thomas D. Jones, mission specialist, and Mark L. Polansky, pilot, change out lithium hydroxide canisters on the mid deck of the Earth-orbiting Space Shuttle Atlantis.

The space shuttle uses an absorption method to remove carbon dioxide (CO_2). The absorption of carbon dioxide is accomplished in a chemical reaction using a sorbent known as lithium hydroxide (LiOH). This method relies on the exothermic reaction of lithium hydroxide with carbon dioxide gas to create lithium carbonate (Li_2CO_3) solid and water (H_2O). Lithium hydroxide is an attractive choice for space flight because of its high absorption capacity for carbon dioxide and the small amount of heat produced in the reaction. Disadvantages include the irreversibility of the chemical reaction. This causes the replacement of lithium hydroxide canisters to be a daily activity during space shuttle flights. There is also the potential for some toxicity within the space shuttle cabin due to the lithium hydroxide dust that could be ingested by the crew. Before a space shuttle mission, EECOM flight controllers and crewmembers receive training that ensures correct precautions and procedures are followed while replacing the lithium hydroxide canisters.

AP Course Topics

Reactions

- Thermodynamics
    - First law: change in enthalpy; heat of formation; heat of reaction; Hess's law; heats of vaporization and fusion; calorimetry
    - Second law: entropy; free energy of formation; free energy of reaction; dependence of change in free energy on enthalpy and entropy changes
    - Relationship of change in free energy to equilibrium constants and electrode potentials

NSES Science Standards

Unifying Concepts and Processes
- Evidence, models, and explanation
- Change, constancy, and measurement

Physical Science
- Conservation of energy and increase in disorder
- Interactions of energy and matter
- 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 Contaminate Control Cartridge (CCC), which contains lithium hydroxide, is used to remove CO_2 from the space shuttle cabin. The removal of the CO_2 is represented by the following equation:

$$2LiOH_{(s)} + CO_{2(g)} \rightarrow Li_2CO_{3(s)} + H_2O_{(g)}$$

A. The removal of the CO_2 occurs in two steps. Determine the value of the Standard Enthalpy change, ΔH°_{rxn}, using the following information:

$$LiOH_{(s)} + H_2O_{(g)} \rightarrow LiOH \cdot H_2O_{(s)} \qquad \Delta H^\circ_{298} = -61.27\ \tfrac{kJ}{mol}$$

$$Li_2CO_{3(s)} + 3H_2O_{(g)} \rightarrow 2LiOH \cdot H_2O_{(s)} + CO_{2(g)} \qquad \Delta H^\circ_{298} = -28.18\ \tfrac{kJ}{mol}$$

Use Hess's Law

Step 1: Take first equation and multiply by 2 and multiply ΔH°_{298} by 2

$$2 \cdot \left(LiOH_{(s)} + H_2O_{(g)} \rightarrow LiOH \cdot H_2O_{(s)}\right) \qquad 2 \cdot \left(\Delta H^\circ_{298}\right) = 2 \cdot \left(-61.27\ \tfrac{kJ}{mol}\right) = -122.5\ \tfrac{kJ}{mol}$$

Step 2: Take second equation and reverse it (Change the sign of ΔH°_{298})

$$2LiOH \cdot H_2O_{(s)} \rightarrow Li_2CO_{3(s)} + 3H_2O_{(g)} \qquad \Delta H^\circ_{298} = +28.18\ \tfrac{kJ}{mol}$$

Step 3: Add two equations together to get the overall equation and add ΔH°_{298} from each equation to get the standard enthalpy change.

Overall equation: $2LiOH_{(s)} + CO_{2(g)} \rightarrow Li_2CO_{3(s)} + H_2O_{(g)}$

Standard Enthalpy Change:

$$\Delta H^\circ_{rxn} = \left(-122.5\ \tfrac{kJ}{mol}\right) + \left(+28.18\ \tfrac{kJ}{mol}\right)$$

$$\Delta H^\circ_{rxn} = -94.32\ \tfrac{kJ}{mol}$$

B. Determine the Standard Entropy change, ΔS°_{rxn}, for the removal of CO_2 at 298 K using the following information:

Substance	$S^\circ_{298}\left(\frac{J}{mol\,K}\right)$
$LiOH_{(s)}$	42.8
$CO_{2(g)}$	213.7
$Li_2CO_{3(s)}$	90.2
$H_2O_{(g)}$	189.0

$$\Delta S^\circ_{rxn} = \left[1\,mol \cdot \left(S^\circ_{298}\ Li_2CO_{3(s)}\right) + 1\,mol \cdot \left(S^\circ_{298}\ H_2O_{(g)}\right)\right] - \left[2\,mol \cdot \left(S^\circ_{298}\ LiOH_{(s)}\right) + 1\,mol \cdot \left(S^\circ_{298}\ CO_{2(g)}\right)\right]$$

$$\Delta S^\circ_{rxn} = \left[1\,mol \cdot \left(90.2\,\tfrac{J}{mol\,K}\right) + 1\,mol \cdot \left(189.0\,\tfrac{J}{mol\,K}\right)\right] - \left[2\,mol \cdot \left(42.8\,\tfrac{J}{mol\,K}\right) + 1\,mol \cdot \left(213.7\,\tfrac{J}{mol\,K}\right)\right]$$

$$\Delta S^\circ_{rxn} = -20.1\,\tfrac{J}{mol\,K}$$

C. Determine the Standard Free Energy change, ΔG°_{rxn}, for the reaction at 298 K. Include units with your answer.

$$\Delta G^\circ_{rxn} = \Delta H^\circ - T \cdot \Delta S^\circ$$

$$\Delta G^\circ_{rxn} = -94{,}360\,\tfrac{J}{mol} - (298\,K)\left(-20.1\,\tfrac{J}{mol\,K}\right)$$

$$\Delta G^\circ_{rxn} = -88{,}400\,\tfrac{J}{mol} \quad \text{or} \quad -88.4\,\tfrac{kJ}{mol}$$

D. Is the reaction spontaneous under standard conditions at 298 K? Justify your answer.

The reaction is spontaneous because the value of ΔG° is negative.

E. Calculate the value of the equilibrium constant, K_{eq}, for the reaction at 298 K.

$$\Delta G^\circ = -RT \cdot \ln K_{eq}$$

$$-88{,}400\,\tfrac{J}{mol} = \left(-8.314\,\tfrac{J}{mol\,K}\right)(298\,K)\ln K_{eq}$$

$$\ln K_{eq} = \frac{-88400\,\frac{J}{mol}}{\left(-8.314\,\frac{J}{mol\,K}\right)(298\,K)}$$

$$\ln K_{eq} = 35.7$$

$$K_{eq} = 3 \times 10^{15}$$

Scoring Guide

Suggested 10 points total to be given.

Question		Distribution of points
A	*2 points*	1 point for application of Hess's Law 1 point for correct calculation of ΔH°_{rxn}
B	*2 points*	1 point for using correct equation 1 point for correct calculation of ΔS°_{rxn}
C	*2 points*	1 point for using correct equation 1 point for correct calculation of ΔG°_{rxn} and correct units
D	*2 points*	1 point for predicting reaction is spontaneous 1 point for correct justification
E	*2 points*	1 point for using correct equation 1 point for correct calculation of K_{eq}

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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