MATH AND SCIENCE @ WORK

AP* CHEMISTRY Student Edition

SPACE SHUTTLE PROPULSION SYSTEM

Background

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.

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 re-entry 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 controllers in the Space Shuttle MCC is the Propulsion (PROP) Officer. The PROP position requires knowledge of fluid mechanics and extensive training in propulsion systems. This flight controller monitors two propulsion systems, the Orbital Maneuvering System (OMS) and the Reaction Control System (RCS). Both systems use propellants to produce the thrust for the orbiter of the space shuttle.

Figure 1: Technicians at Kennedy Space Center don Self-Contained Atmospheric Protective Ensemble (SCAPE) suits. These special suits are used by employees involved in hazardous chemical operations including the task of loading the propellant for the space shuttle.

Propellant is a general term for either of the two part chemical constituents (fuel or oxidizer) that is required to support the combustion process and deliver thrust in a rocket engine. The orbiter's OMS

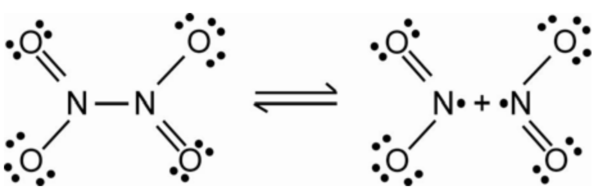
and RCS fuel is monomethyl hydrazine (CH_3NHNH_2), and the oxidizer is dinitrogen tetroxide (N_2O_4). This particular propellant combination is extremely reactive and spontaneously ignites on contact (hypergolic) with each other. This chemical reaction ($4CH_3NHNH_2 + 5N_2O_4 \rightarrow 9N_2 + 4CO_2 + 12H_2O$) occurs within the engine's combustion chamber. The reaction products are then expanded and accelerated in the engine bell to provide thrust. Due to their hypergolic characteristics these two chemicals are easily started and restarted without an ignition source, which make them ideal for spacecraft maneuvering systems.

Over a two day period, workers at the Kennedy Space Center load the fuel and oxidizer into the space shuttle while it sits on the launch pad. They must use extreme safety precautions when loading these propellants into the Orbiter OMS and RCS. When the space shuttle lifts off it is carrying more than 1200 kg of monomethyl hydrazine and 2000 kg of dinitrogen tetroxide.

When monitoring the propellant associated with the OMS and RCS systems, the PROP Officer looks for any conditions that are giving values that are different than expected (off nominal). Leak detection software, and fault detection and annunciation software will alarm if there are any leaks or if any parameters are out of specified limits. The PROP officer uses predetermined procedures, flight rules, and other certified documentation to determine the cause of a problem and to know what actions to take. Communication with other flight controllers is also crucial when resolving any problems that arise.

Problem

The monomethyl hydrazine decomposes into a methyl group and nitrogen. Dinitrogen tetroxide decomposes to form an equilibrium mixture with nitrogen dioxide according to the reaction equation illustrated below.



A. Use the illustrated reaction equation to answer the following:

   I. Identify the molecular geometry of N_2O_4.

   II. Identify the hybridization of the N atoms in N_2O_4.

   III. How many sigma bonds and pi bonds are in N_2O_4?

B. Predict the sign of $\Delta H°$ for the reaction. Justify your answer.

C. Predict the sign of $\Delta S°$ for the reaction. Justify your answer.

D. Sketch a graph that represents the relationship between $\Delta G°$ and temperature for the reaction given above and explain the graph in terms of the relationship $\Delta G° = \Delta H° - T\Delta S°$. Assume that $\Delta H°$ and $\Delta S°$ are independent of temperature.

E. The reaction mixture of N_2O_4 and NO_2 is an equilibrium mixture. If heat is added to the mixture at constant pressure explain why the concentration of N_2O_4 decreases.

F. The value of K_{eq} at 25°C is 5.0×10^{-3}. If the temperature is raised to 150°C will the K_{eq} be greater than, less than, or equal to this value?

G. Discuss any potential environmental effects that N_2O_4 and NO_2 could pose if released from the space shuttle into the atmosphere. Justify your answer.