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LITHIUM BATTERY SPACE EXPERIMENT

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ABSTRACT

The In-Space Technology Experiments Program selected the Jet Propulsion Laboratory to conduct a Phase A study of the Lithium Battery Experiment. The experiment will mark the first time a rechargeable lithium battery will be flown in space. The operation of the battery involves lithium deposition and dissolution processes. Micro gravity influences these processes significantly. The experiment will check the rate capability, discharge voltage, capacity and the phenomena affecting cycle life. The paper describes the design and methodology of this experiment.

INTRODUCTION

The In-Space Technology Experiments Program selected the Jet Propulsion Laboratory to conduct a Phase A study of the Lithium Battery Experiment. The experiment will mark the first time a rechargeable lithium battery will be flown in space. It is very important to conduct space tests of these new battery chemistries. Lithium cells employ organic electrolytes with tow concentration of charge carriers. In such electrolytes, limiting current can be a strong function of microgravity. The operation of the battery involves lithium deposition and dissolution processes. Microgravity may influence these processes significantly.

The experiment will check the effects of microgravity on rate capability, discharge voltage, capacity and the phenomena affecting cycle life. Two types of experiments will be conducted. The first set of tests will be set up to determine the effects of electrical performance characteristics such as rate capability, capacity, operating voltage, and specific energy. The electrical performance tests will be conducted at increasing discharge rates and constant charge rate. The second series of tests will investigate the cycle life phenomena. The charge rates will be sequentially increased while maintaining a constant discharge rate for each group of cells. The flight test sequence will be repeated on the ground. Four types of cells will be tested: lithium titanium disulfide, lithium ion, lithium polymer and lithium ion polymer. The cells will all be 1 Ah size. There will be enough cells in each test to assure good replication of results.

In the post flight analysis of cells, the individual cell capacities and weights will be measured. The flight cells and control cells will be disassembled in a dry box. All plates, separators and electrolytes will be examined at the surfaces and in the cross sections. SEM

This work was performed by the Jet Propulsion laboratory, California institute of Technology, under contract with the National Aeronautics and Space Administration.

inspections will be conducted. The main value of the experiment will be in establishing possible correlations of experimental data with theory. These correlations will be used to suggest design modifications to improve performance of lithium batteries in microgravity.

IMPORTANCE OF LITHIUM BATTERIES

Rechargeable lithium batteries have higher specific energy and energy density, compared to state-of the art batteries such as Ni-Cd and Ni-H2 as shown in Figure 1 and 2. (1)

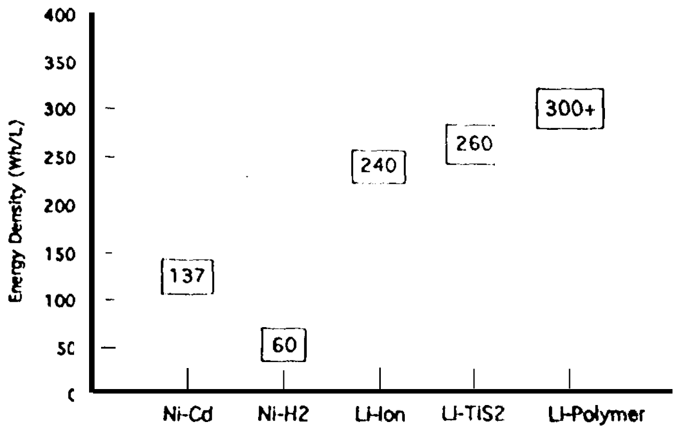


Figure 1 Comparison of Specific Energy of Batteries

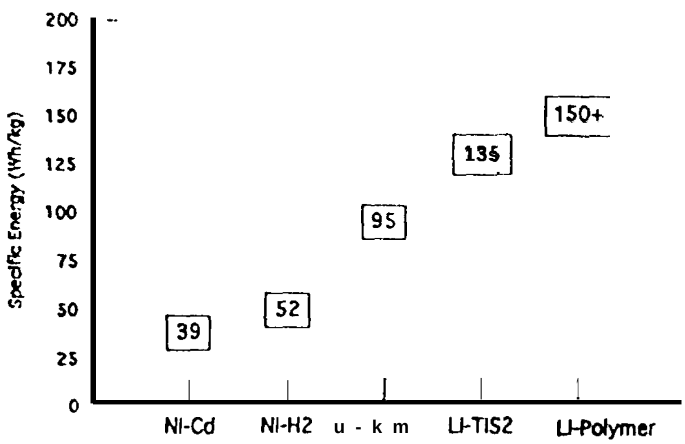


Figure 2 Comparison of Energy Densities

Inspection of these figures reveals that lithium batteries have a 3-5 times higher specific energy (Wh/kg) and energy density (Wh/l) than the nickel-cadmium (Ni-Cd) battery that presently serves as the baseline in spacecraft power systems. These lithium batteries also have 2-3 times the specific energy and energy density of the nickel-hydrogen ($Ni-H_2$) battery used primarily on communication satellites. In addition, these batteries have longer storage life, lower self discharge and no memory effect compared to nickel based batteries. In view of these advantages, these batteries are presently being considered for several commercial/terrestrial applications where weight, volume, and life are critical, These advantages also make these batteries attractive for aerospace applications. For example, the Mars Observer (MO) spacecraft carried a Ni-Cd battery that weighed 33.3 kg and occupied 26.4 liters. Use of a rechargeable lithium battery would save about 24 kg and 21 liters. This weight saving could translate into additional paytoads, more margin for the spacecraft subsystems, or more propellant to extend the mission. Figure 2 gives a comparison of battery mass and volumes for the MO Ni-Cd battery and an equivalent energy secondary Lithium battery.

NEED FOR LI BATTERY SPACE TEST

Lack of the natural convective mass transport process associated with microgravity influence the performance and cycle life capabilities of rechargeable lithium cells. (2,3) Specifically, microgravity environment in an operating spacecraft is most likely to result in reduced electrical output capabilities and require modification to the cell design and operating conditions. to preserve the cycle life capabilities of these cells relative to their operation in the 1 "G" terrestrial environment.

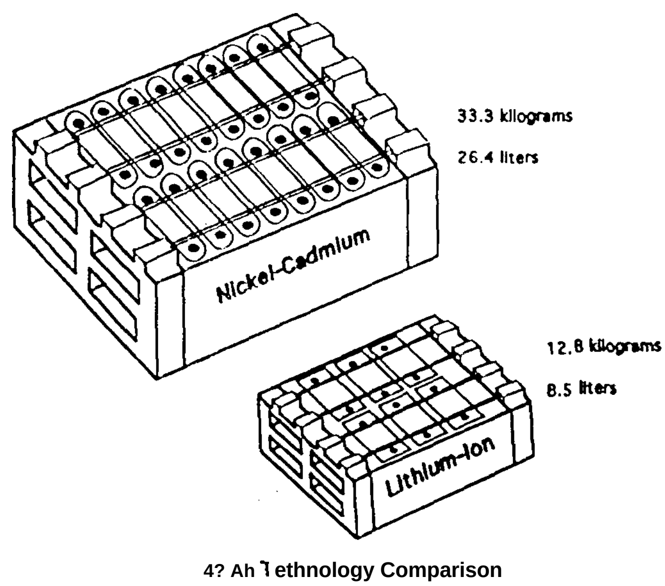


Figure 3. Comparison Between the Mars Observer Battery and an Equivalent Li-Ion Battery

EXPERIMENT OBJECTIVES

The overall objective of the experiment is to determine the effect of microgravity on electrochemistry and performance characteristics of rechargeable lithium cells and identify modifications to design and operational parameters to enhance performance and cycle life of these cells in space. The four specific objectives of the experiment are detailed below:

1) Determine the relative magnitudes of the transport processes including natural convection, diffusion, migration, and Marangoni convection during the operation of lithium cells in space and ground.

2) Determine the influence of microgravity on the electrical performance characteristics of rechargeable lithium cells and compare the electrical performance of these during flight and in the ground tests. The performance characteristics of concern are: (a) rate capability, (b) discharge voffage, (c) capacity, (d) specific power and power density, (e) specific energy and energy density.

3) Determine the effects of microgravity on cycle life characteristics of candidate rechargeable lithium cells and compare with the cycle life capabilities of these cells on ground.

4) Determine the relative merits of lithium cells (liquid electrolyte vs. gelled polymer electrolytes and lithium metal anode vs. intercalation type anode) for space applications.

METHODOLOGY

Three well-defined activities are proposed to meet the proposed objectives of the experiment: (1) Electrical Performance Testing (2) Cycle Life Performance Testing and (3) Modeling and Analysis.

The first activity is aimed at determining the effects of microgravity on electrical performance characteristics of the cells and the second activity is aimed at determining the effects of microgravity on charge current density that governs the cycle life performance of the cells. The aim of the modeling and analysis activity is to develop a basic understanding of the effects of microgravity on the electrochemistry of the lithium batteries and identify the most promising cell type for the space applications. This activity involves modeling the transport processes in the various lithium batteries, analysis of the flight and ground test data and destructive physical analysis of the cells. These flight tests will be carried out over a period of 5 days and possibly longer for an extended flight. The "cells will be housed in a Hitchhiker S. The experiment will be autonomous and will interface with the carrier for dafa down link and electrical power for control systems. The necessary power for this experiment will be obtained from the shuttle electrical bus. Details of the cell types, tests/activities, experimental hardware, and data analysis are discussed in the following sections. A summary of the proposed activities, the objectives and resultant benefits are discussed in Table 1.

Test/Analyses	Objective"	Benefits
1. Transport Analyses	Determine impact mass transport reduction by natural convection on electrochemistry	Improve understanding of transport in microgravity and 1G. Identify novel methods to improve capabilities
2. Electrical Performance Test	Determine performance loss of cells in space	Identify optimum performance design parameters
3. Cell Cycle Life Test	Determine impact microgravity on cycle life	Identify optimum parameters for long cycle life
4. Comparison of Cell Types for Space	Determine relative the impact of microgravity on cell types	Identify optimum cell type for space. Minimize flight development/ qualification time and cost

7 able 1. Objectives and Benefits of Test/Analyses

El ECTRICAL PERFORMANCE TESTS

These tests are intended to establish the electrical performance characteristics of the cells under microgravity during flight. An identical test will be carried out on the ground before the flight test.

Test Articles and Conditions

•Cell types: 1 AH size of each type Li-TiS2, Li-ion, Li-Polymer, and Li-Ion Polymer

•Total Number of Cells = 16

• Repetition = 4x

Cycle #	Charge Rate	Discharge Rate
1	C/10	C/10
2	C/10	c/5
3	C/10	c/2
4	C/1 o	c
5	C/10	2C

The tests consist of continuous cycling of groups of cells over a range of discharge rates frOm about C/ 10 to 2C (exact values will be established from the limiting discharge current tests as described above). The cells are to be divided into four groups. Each group will consist of four cells of each type (Li-TiS_2, Li-ion, Li-Polymer, and Li-Ion Polymer). Each group will be cycled continuously at full capacity (100% DOD) in accord with the above sequence.

CYCLE LIFE TESTS

These tests are intended to establish the cycle life performance characteristics of the cells under microgravity. An identical test will be carried out on the ground before the flight test.

The tests consist of continuous cycling of groups of cells at 50% DOD. In this test, the cells will be charged at various charge rates and discharged at a constant discharge rate. A summary of the test is given below.

Test Articles and Conditions

- Cell types: 1 AH size of each type Li-TiS_2, Li-ion, Li-Polymer, and Li-Ion Potymer
- Depth of Discharge: 50%
- Total number of cells; 4x4x3=48

Group #	Charge Rate	Discharge Rate
1	C/10	c/2
2	C/5	c/2
3	C/2	c/2

The cells are to be divided into three groups. Each group will contain 16 cells comprised of 4 cells of each type (Li-TiS_2, Li-ion, Li-Polymer, and Li-Ion Polymer). Each group of 16 cells will be cycled continuously at partial capacity (50% DOD) in accord with the following sequence. The calls will be cycled at least 20-40 times depending on the duration of the flight.

MODELING AND ANALYSIS

The aim of the modeling and analysis activity is to develop a basic understanding of the effects of microgravity on the electrochemistry of the lithium batteries, identify the most promising cell type for space applications and optimize cell design. This activity involves modeling of the transport processes in various lithium batteries, analysis of the flight and ground test data and destructive physical analysis of the cells.

MISSION DESCRIPTION

Lithium cells will be mounted in a Hitchhiker canister system aboard the space shuttle. The minimum objectives of the experiment can be accomplished in five days of a Shuttle flight. Longer flight times will bring additional data. There are no requirements levied on the Shuttle orbit, inclination or pointing. The experiment requires only standard services offered by the Hitchhiker facilities.

A successful experiment will require the simultaneous execution of the rate capability study and the cycle life test. Lithium cells shall be contained within the Hitchhiker canister at one atmosphere and subjected to thermal setup and testing. Test results including cell and canister temperature, charge and discharge current and cell voltages will be sent via low rate data to the orbiter OPS recorder and finally relayed to the ground team.

FLIGHT MEASUREMENTS

Flight cell operating voltage, current and temperature will be measured during the rate capability study and the cycle life test. Identical testing will be Conducted on the ground. Upon completion of all testing, both flight and control cells will be disassembled in a dry box. Residual cell capacities and weights will be measured. Visual and photographic inspections will follow with an analyses of plates, separators and electrolytes for dendrite formation.

The experiment will require a total of 64 test cells. This assumes four different lithium chemistries will be flown using 16 cells of each type. A voltage analysis shows that a minimum of four cells must be exposed to any given phase of testing to provide meaningful results about that particular chemistry with a probability of 95%.

The rate capability study will require a total of 16 cells (4 each of 4 chemistries). The initial state of charge of the cells will be 100%. Each cell will undergo at least 20 cycles of discharge and recharge. The discharge rates will vary between 0.1 and 1.0 amps. The charge cycle will atways be constant at 0.2 amps. The results of the test will be analyzed to determine the electrical performance characteristics including capacity, capability and specific energy.

The cycle life test will use 48 cells (12 each of 4 chemistries). Three subtests will be run using 4 cells of each chemistry. All subtests will incorporate a discharge/charge cycle. The subtests will differ in the charge rates (0.05, 0.1 & 0.2 amps respectively).

MISSION REQUIREMENTS

The 58 kg experiment will require approximately 80 watts of power. Lithium cells under test will be housed in aluminum blocks for containment, thermal stability and safety within a single, standard 28 liter Hitchhiker canister. The canister shall be purged with dry nitrogen at one atmosphere and configured to dissipate heat through the top cover with the rest of the canister blanketed. Both the Hitchhiker avionics and the experiment control electronics shall work in sync to maintain the test cells at approximately 20"C for the duration of the experiment.

The experiment will be autonomous incorporating the orbiter low rate data interface and asynchronous uplink for ground intervention as deemed necessary to maximize the experimental results. Electrical power shall be derived from the Hitchhiker system. A maximum of 9600 watt-hours shall be required for experiment execution.

According to the preliminary thermal analysis the experiment controller housed within the canister will maintain lithium cells at approximatety 20 "C. The same analysis indicates the common shuttle orbital thermal attitudes are acceptable. Test cells showing any indication of overheating will be disconnected from the experiment. Disconnection will occur automatically as a function of hardware or the experiment control software when test limits are exceeded. In addition, use of the asynchronous uplink will be available to isolate and or reconnect test cells as necessary.

CONCEPTUAL DESIGN

The experiment consists of the charge and discharge of up to four lithium chemistry cell types with associated data gathering and control as shown in figure 5. The test sequencer and controller will be processor based and designed to select charge/discharge rates while formatting test cell voltage, current and temperature. The formatted data is then transferred to the Hitchhiker avionics and orbiter OPS recorder. The controller is intended to provide real time access to the experiment and hence, will have the capability of being reprogrammed on-Orbit.

Critical test cell parameters including voltage and temperature will be automatically sensed and fed back to the charge regulators and test sequencer. Test cells will automatically be disconnected to prevent thermal stress and runaway conditions. In addition, all test cells will be fuse protected.

The test load banks, one fixed and one selectable, shall be resistive in nature and comprised of either discrete or electronic loads. Loads will be designed to minimize back EMF and potential damage to relay contacts and the cells under test. The experiment schematic is shown in figure 6.

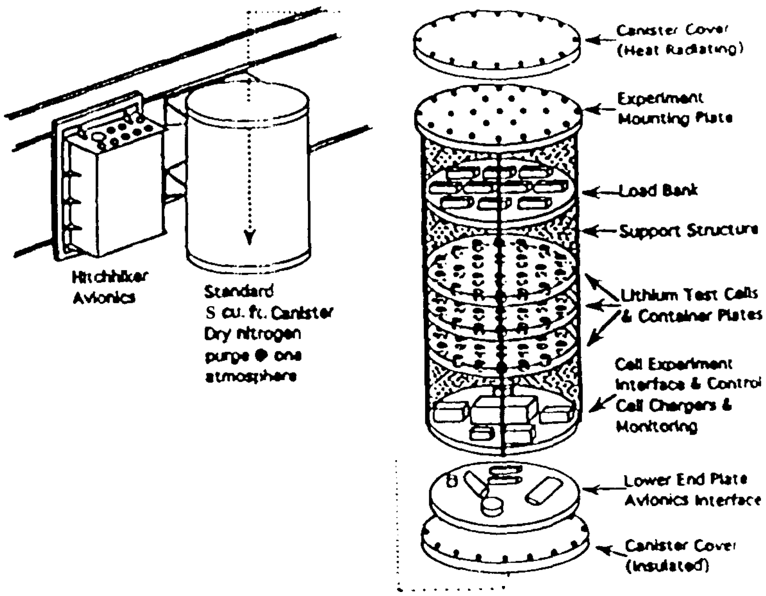


Figure 4. Experiment Physical Configuration

Analog multiplexer will provide both differential and single ended conditioning including thermistor excitation as necessary. Multiplexer outputs will be routed through an analog to digital converter with 12 bit resolution. Digitized data is then formatted for transfer to the Hitchhiker low rate data system. The system shall be capable of sampling cell data at a maximum rate of four ceils per second measuring four parameters per cell. The design can transfer 100 bytes per second at 1200 baud. Once the data is received by the Hitchhiker ground operations center, it shall be transferred into the experiment ground support equipment for analysis. The ground support equipment (GSE) shall be comprised of three primary and three backup computers running Spacecraft control Language (SCL). The GSE shall have the ability to command and reconfigure the experiment in flight.

SUMMARY

The experiment is aimed at determining the effect of microgravity on electrochemistry and performance characteristics of rechargeable lithium cells. The approach will involve conduct of flight and ground tests on four types of secondary lithium cells, followed by the assessment of the results. The work will be carried out by a team consisting of JPL, battery manufacturers, government organizations and universities. The successful completion of the In-Step lithium battery experiment is projected to result in improved cell design for aerospace applications and improved understanding of the basic electrochemistry of rechargeable lithium batteries.

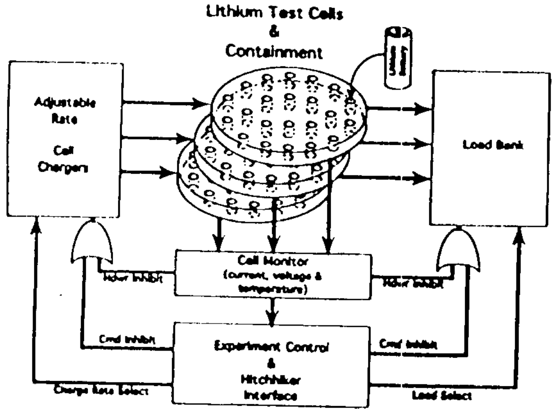
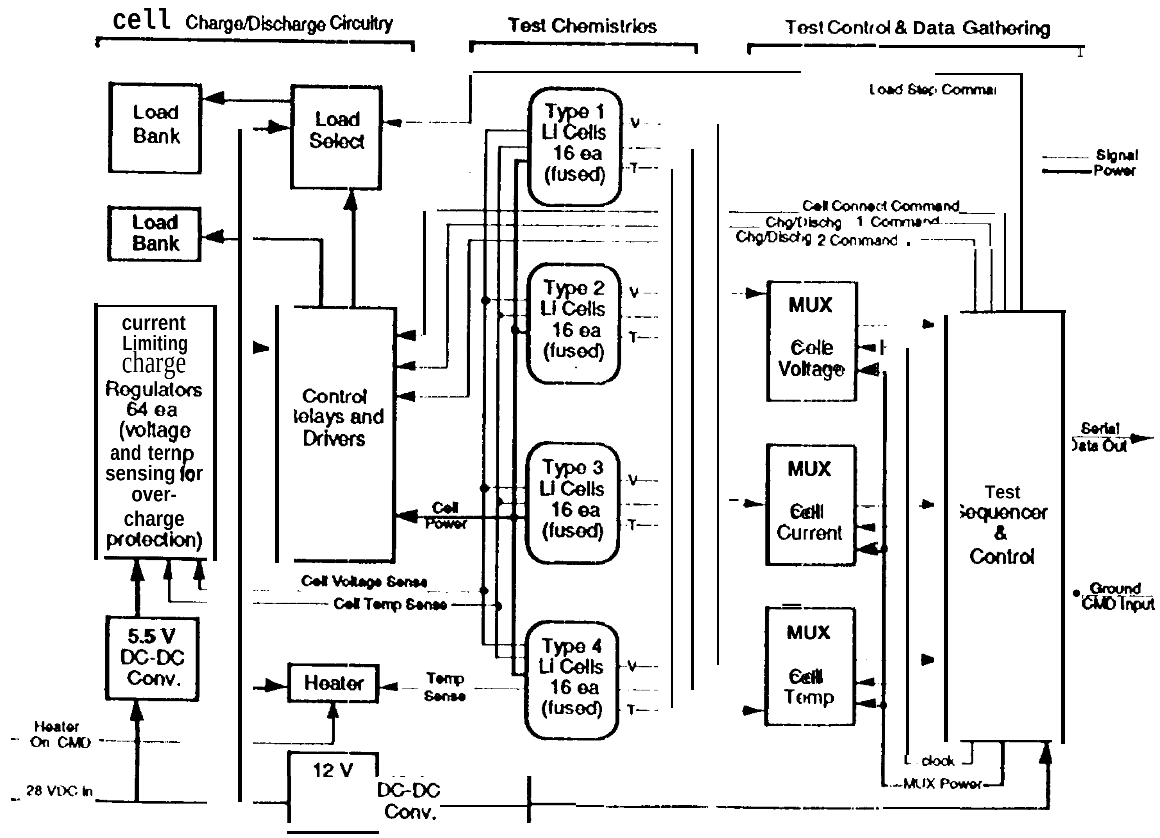


Figure 5 Lithium Cell Test Concept

Lithium **Battery** Experiment Schematic



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