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Photoelectric Charging by Ultraviolet Light of a Lunar Dust Simulant in a Microgravity Environment

Microgravity Research Team 2008

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Proposal for NASA Reduced Gravity Student Flight Opportunities Program

Photoelectric Charging by Ultraviolet Light of a Lunar Dust Simulant in a Microgravity Environment

MRT (Microgravity Research Team)

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Technical/Required Format

Team Information

Table 1 lists the members of this academic year's Applied Flight Research Group of the Microgravity Research Team at Utah State University and their roles within the team.

Table 1. Team Members and Roles.

Flyer	Ground Crew	Faculty Support	Press
Sarah Isert Mechanical/Aerospace Engr.	Troy Munro Mechanical/Aerospace Engr. (Team Contact)	Dr. J.R. Dennison Physics, Professor	MaryAnn Muffoletto PR & Marketing
Vicki Ragsdale Mechanical/Aerospace Engr.	Sydney Chamberlin <i>Physics, Math</i>	Dr. Jan Sojka Physics, Dept. Head	
Dean Lanier Electrical and Computer Engr.			
Lance Petersen Physics			
(Alt.) Alex Wright Mechanical/Aerospace Engr			

Flight Week Preference

First: Flight Week 2: June 4-13, 2009 Second: Flight Week 3: June 18-27, 2009 Third: Flight Week 4: July 9-18, 2009

Advisor/Mentor Request

Not applicable to this project.

Synopsis/Abstract

A microgravity experiment to test the electrostatic behavior of a lunar dust stimulant being charged through the photoelectric effect will expand understanding of the charging characteristics of dust particles and may lead to a possible mitigation solution. With a design based upon Robert Millikan's oil-drop experiment, this experiment is designed to observe the interactions of a lunar dust simulant without the conflicting effect of a dominant gravitational force. The dust particles will be charged by means of a lamp capable of photon energies necessary to emit electrons by the photoelectric effect. In the presence of an axial electric field, the photo-electrons and charged dust will be attracted to opposing sides of a capacitor and net charge over time as well as physical trajectories of the particles can be determined.

Although this experiment is not designed to provide a dust mitigation strategy for lunar regolith, an increased understanding of the charging properties of silica by means of the Microgravity Research Team's experiment benefits the scientific community.

Test Objective

Test Objectives:

The objectives of the experiment are as follows:

- 1) To determine the net charge acquired by silica dust particles over time evolution due to electron emission from the photoelectric effect, under controlled experimental conditions.
- 2) To qualitatively observe the interactions between particles of a charged lunar dust simulant in microgravity.
- 3) To determine the effect of particle size in relation to net charge acquired.

The results of this experiment will increase our understanding of the charging properties of silica dust, a lunar dust simulant.

Hypotheses:

As introduced by the test objectives, our primary and secondary hypotheses are:

- 1) Silicon dust particles will exhibit a charging effect when exposed to ultraviolet light containing sufficient minimum photon energy corresponding to the work function for the compound.
- 2) The rate of charging over time evolution will be constant due to the photoelectric effect being almost instantaneous, but the rate of acceleration of the particles will increase as greater charge is accumulated.

The correlation between photons of a given energy and electron emission of the irradiated surface is discussed in the photoelectric section. The effect should be observed if the photon energy of light used is great enough to exceed the electron affinity of the elements contained in the particle's composition. If no net charging effect is observed for any frequency of light, it will be possible to rule out light as a potential parameter in the charging of planetary dust.

This experiment is not a follow-up to a previous experiment.

Test Description

The Microgravity Research Team (MRT), formerly Get Away Special Team, at USU participated in NASA's Reduced Gravity Student Flight Opportunities Program in 1999 (Wright) with an experiment testing the collisions and segregation of granular materials in microgravity. Dr. JR Dennison, faculty advisor for the team, is part of the Gateway Lunar Science Consortium which is currently part of a project in response to NASA's call for proposals to research lunar regolith. The current MRT team is interested in the effects of charging on dust and our experiment will test what effect the photoelectric effect has on charging borosilicate dust. This may be of particular interest to NASA in that the interactions of this charged dust could be analogous to charged dust found on the Moon and Mars. The team does not intend to propose a mitigation strategy like that of the University of Texas (Belden); rather our test will determine charging characteristics of a lunar simulant.

On the Moon, the causes of charging often stem dust interactions with plasma electrons, bombardment from solar wind (including the sputtering of atoms from the lunar surface), and photoelectron currents on the planet surface (Halekas). A basic understanding of dust composition, physical properties of lunar regolith, the photoelectric effect, and Millikan's oil-drop experiment will establish the basis for our test.

This test is not a free float experiment.

Lunar Dust and Simulant Selection

When men first landed on the Moon in 1969, one of their missions was to analyze the Moon's surface properties. This included gathering samples, observing properties, and performing simple experiments on their surroundings. Many interesting things were discovered about the lunar surface in general and lunar dust in particular.

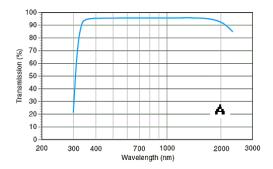
Studies have determined the average composition of several lunar dust samples through use of electron microprobe analyses of samples obtained by means of a cellulose stripping technique. (Robertson). Previous results (Robertson and Carr and Proudfoot) indicate that the compound with the largest proportion in the composition of the lunar dust is SiO_2 at 39 %, with other major compounds being FeO, CaO, and Al_2O_3 . This understanding of lunar dust composition as well as safety, availability and cost considerations cemented the selection of a silicon dioxide (SiO_2) based compound for our experiment.

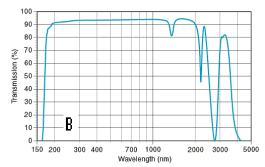
Other interesting properties of lunar dust pertained to the dust's adhesive properties. The dust tended to stick to everything. When one of the Lunar Module's struts was kicked, dust fell off the spacesuits, but left a stain indicating that particles still adhered to the surface. The spherical shaped particles were found to adhere more strongly that the jagged and sharp particles (Scott 144). The dust, however, was not only a cosmetic problem but an operational one. When the television cable became coated with the dust it was difficult to distinguish it from the lunar surface, causing Astronaut Armstrong to repeatedly become entangled in the cable. When the Lunar Equipment Conveyer was brought into the spacecraft cabin it brought dust in with it,

causing a housekeeping problem. When pulleys were operated, the dust tended to collect in them, causing the pulleys to bind (Apollo). Numerous other examples of dust problems occurred on other Apollo missions, including allergy attacks, dust collecting in seals, and abrasion of various components due to dust. The small, sharp glass particles are potentially responsible for damage to spacecraft, computers, and crew of future lunar missions.

For this experiment, the lunar dust stimulant borosilicate glass (BK7, approximate composition from manufacturer: 70% silica, 10% boron oxide, 8% sodium oxide, 8% potassium oxide, and 1% calcium oxide) was selected. One of the primary reasons was that most lunar samples are primarily silicates with heavy impurities (Keller). BK7 is a commonly manufactured material that can be made with highly uniform composition, size distribution and particle shape. This makes analysis of experimental results much more straightforward. Although precautions still must be taken with BK7, it poses much less of a safety hazard to researchers than other silicate glasses due to its amorphous structure and rounded particle shape.

BK7 is also very similar in behavior to lunar silicate glass with regards to its transmission and absorption of light. From its transmission curve, pure silicate glasses transmit less than 10% of incoming light with energies greater than 8.9 eV (Fig. 1(b)). The addition of boron lowers the 10% transmission edge to 4.1 eV (Sickafoose; also see Fig. 1(a)) Measurements of photoyields of lunar dust samples found a comparable





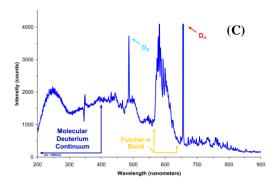


Fig. 1 Optical transmission curve of (A) BK7 Optical Glass and (B) Fused Silica/Quartz. (Esco). (C) Emission spectrum of deuterium Ocean Optics HR2000 spectrometer (Ocean Optics).

absorption edge at 5 eV (Feuerbacher). Due to a similarity in their transmission curves, results obtained from an experiment with BK7 will be able to be related to properties of silicate glass.

The experiments proposed here mimic Millikan's work by recording the trajectories of lunar dust particles with video as the become charged through the photoelectric effect while subject to radial electrostatic forces from the voltage across the cylindrical capacitor. This extends Millikan's work by investigating the motion of charged dust particles in the greatly reduced gravity field of the C-9, which allows the influence of electric field to be better isolated. Table 3 shows the electric field required to balance gravitational forces for our particles size distributions and apparatus geometry (assuming a charge of one electron per dust particle) for terrestrial, Lunar, Martian, and C-9 gravitational fields. As can be seen, the voltages required for this are very large and exceed the electrostatic breakdown voltage in air for all but the C-9 case. Our

proposed experiments will use potentials of 50%, 100%, 300%, and 500% of the equilibrium potential to investigate how "turning off" gravity will affect charge trajectories and particle agglomeration. The required potentials of up to 1000 V are reasonably attained.

Thus, the use of the lunar dust simulant BK7 and filtered deuterium lamps provide an inexpensive, effective way to study the photoyield characteristics of potential harmful lunar dust in a safe and controlled environment.

The Photoelectric Effect

Ultraviolet solar radiation on the sun side of the Moon charges dust positively (Feuerbacher; Abbas). Since the Moon has no atmosphere, ultraviolet light is intense and charging large. On the dark side, solar wind charges dust negatively (Anderegg). An easily reproducible, safe, and inexpensive method of charging by lower photon energies is through the photoelectric effect.

Using quantum theory in the early 1920's, Albert Einstein worked to unravel the mysterious interaction that takes place between a solid and a light source with certain characteristics. In 1921 he was awarded the Nobel Prize for this effort (Beiser). In our experiment, lunar dust simulant will be charged using the photoelectric effect. Robert Millikan was awarded the 1923 Nobel Prize, in part for his detailed experimental investigations of the photoelectric effect. Together, Einstein and Millikan showed that the energy of the electrons emitted from a surface are directly proportional to the frequency, ν , of the light striking the surface, this relationship is given by:

$$E_{el} = h\nu + \Phi \tag{Eq. 1}$$

where h is and the work function of the solid, Φ , is the minimum frequency required to remove an electron from the sample surface. The work function for BK7 and lunar dust samples have been measured to be 4.1 eV (Sickafoose; Dennison) and greater than or equal to 5 eV (Feuerbacher), respectively. The solar radiance spectrum (Grard) has a significant intensity in the ultraviolet about 5 eV especially from the 10 eV H Lyman alpha line, so photoelectric charging is a significant effect in space and on the lunar and Martian surfaces where atmospheric absorption of ultra violet light is minimal. To conduct experiments on photo-emission of BK7 lunar simulants, a source with high ultraviolet intensity above 5 eV is required.

In addition to measuring the magnitude of the photoelectric charging of lunar dust simulant, the affect of charging on the motion and agglomeration of dust particles will be studied. The basic approach is similar to Millikan's oil-drop experimental apparatus that was designed around the turn of the 20^{th} century.

In 1923, Robert Millikan was awarded the Nobel Prize in physics for his work on calculating the charge of an electron as well as his work on the photoelectric effect. Fittingly, our studies building on Millikan's oil-drop experiments that also involved Henry Fletcher, will take place during the centennial year of these experiments that began in 1909 (Noble Lectures).

The experiment was based upon the understanding that charged particles are affected by an electrostatic force in the presence of electric and gravitational fields. The scientific community

of Millikan's era understood the forces of gravity and electromagnetism, and with this understanding the experiments variables were mass of the oil drop, the force due to gravity, air resistance, electrostatic forces from the apparatus on the oil drop, and the charge of the electron. Through use of Stokes' Law, Millikan was able to determine the mass of each oil drop and by so doing determine the force of gravity and the electrostatic force from the electric field between the charged plates required to balance the force of gravity. Then all of these forces were calculated and entered into one equation to determine the charge of the electron (Knight).

Mechanical Design

The overall mechanical design of the experiment has been driven by the dust particle size and charging properties, which determine the physical dimensions required to balance the gravitational forces with electrostatic forces at low enough voltages to avoid electrostatic breakdown. This dictates a cylindrical chamber geometry with diameter of 10.2 cm inside diameter and length 30.5 cm. Additional design constraints include:

- 1. The need for a small, low cost system that allows several duplicate systems to allow for tests of multiple applied voltages, particle size, and redundant measurements.
- 2. Durable rigid construction to minimize damage during flight.
- 3. Sealed construction to minimize contamination and safety concerns from dust inhalation or exposure to intense ultraviolet radiation.
- 4. Simple operation that can be performed during weightlessness through extensive use of computer automated experimental control and data acquisition.

Figure 3 is a CAD drawing of the experiment canister showing dimensions and structural parts. Figure 5 on page 18 shows a block diagram of the chamber, electronics, computer automation, and air circulations systems involved. A prototype is built and being tested in our lab consisting of a black ABS (Acrylonitrile butadiene styrene) pipe segment that is a foot long and sealed on both ends. The inside wall of the tube is lined with adhesive metalized Mylar film. There is a wire down the center of the tube to create an axial electric field in the capacitor. The presence of the electric field in the capacitor, caused by an applied varying voltage difference, will cause charge particulates to be separated and a ultraviolet light will provide the means of charging for the dust. Positively charged particles will be attracted to the negatively biased film while the photoelectrons will be attracted to the positively biased central wire. After each run of the experiment, an ionizing hair dryer will neutralize the charge of the particles and keep the dust from grounding itself with the air.

The light source required is a broad band source with high intensity both above and below the BK7 absorption edge at 4.1 eV. Deuterium lamps with quartz envelopes satisfy these require requirements and are readily available at low cost as UV-C sources components of inexpensive commercial air purifiers. Figure 1(c) shows the emission spectrum, measured by the USU Materials Physics group, of the Secure Air 9W Deuterium lamp to be used in our experiments. The spectrum shows similar radiation intensity above and below the absorption edge. The photoyield current can be estimated to be on the order of 15 pA for this source in the proposed sample geometry, assuming a 1 gram BK7 sample with a quantum efficiency of about $2*10^{-7}$ electrons per photon for lunar dust (Feuerbacher), greater than 90% absorption for 10μ m lunar

dust particles at greater than 5eV (Noble). A longpass IR filter (Edmond Optics NT47-618) will be used for high energy tests to block light below 2 eV from entering the chamber thereby reducing chamber heating. A shortpass visible (Edmund Optics NT47-810) filter will be added for low energy measurements to block UV light about 3.1 eV.

The electrometers to be built for the experiment, following a simple modular design used by the USU Materials Physics group (Thomson) shown in Fig. 6, and can readily measure 0.1 pA, well below the predicted photocurrent. Charging of the lunar simulant dust particle will be determined by measuring the ion current from the cylindrical capacitor and the electron current to the central wire during ultraviolet illumination. The principle is essentially that used for vacuum ionization gauges.

The experiment will consist of three to four canisters filled with dry (anhydrous) gaseous nitrogen, at a pressure slightly greater than the pressurized aircraft, which will be mounted together by foam tape into a triangular or square formation with the air ionizer and fan located on the side of the canister cluster. Figure 2 is a CAD representation of the three canister assembly that will be bolted to the floor. Each test canister will be illuminated for viewing purposes by a low energy LED. This is to be able to compare results but also to allow the camera to record the dust in the control tube in a lighted environment. Each canister will be filled with a different particle size: 18 μm, 2 μm, 60 μm (if there is sufficient funding for a fourth tube), and a 18 µm control dust.

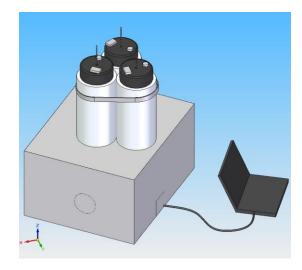


Fig. 2: View of assembled apparatus.

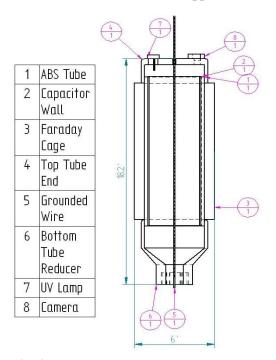


Fig. 3: Chamber cross section.

The exterior of the tube will be wrapped in a metal Faraday shield to negate any outside electric fields, while the bottom of the tube will be attached to a USB missile launcher ('thumper') that will provide a puff of air to distribute the dust into the capacitor. At the end of each experimental run, the ionized air will permit the particulates to fall to the bottom of the canister onto the 'thumper' to be reset for the next run. The ultraviolet light source, filters, LED, camera, and air tubes are located at the top of the canister. To prevent leakage of N₂ gas, all connections will be sealed and to prevent unwanted irradiation of ultraviolet light outside of the tube, an Edmund Optics UV longpass filter will be the window through which the camera is placed over.

Table 2. USU Test Matrix

Light Energies	Voltage			
	50% (100 V)	100% (200 V)	300% (600 V)	500% (1000 V)
	2µm	2µm	2µm	2µm
> 5eV (unfiltered)	18µm	18µm	18µm	18µm
	60µm	60µm	60µm	60µm
Visible control	18µm	18µm	18µm	18µm
	2µm	2µm	2µm	2µm
< 5eV (filtered)	18µm	18µm	18µm	18µm
	60µm	60µm	60µm	60µm
Visible control	18µm	18µm	18µm	18µm

Additional filters will be alternatively placed in front of the ultraviolet light to allow either all photon energies or energies of less than 5 eV, illustrated by the test matrix on the next page.

Several seconds prior to each session of microgravity, the capacitor will be allowed to charge up to a steady state circuit. At this point the electric field will be at its maximum strength and have the greatest effect on the charged dust. Varying voltage differences of 100 V (50% of breakdown voltage), 200 V (100%), 600 V (300%), and 1000 V (500%) will create an electric field with a magnitudes ranging from 2 kV/m to 20 kV/m across the .0508 m radius of the capacitor as determined by:

$$-V = E \cdot d \tag{Eq. 2}$$

where V is the potential difference, E is the electric field strength, and d is the distance between the electrodes.

Once microgravity has been initiated, no more than 1 g of silica will then be distributed up into the capacitor by means of the USB launcher. When microgravity is in effect, the ultraviolet light will then be turned on and allowed to irradiate the dust for the remaining duration of microgravity, but it will remain on during the time necessary to allow particle motion to complete before weightlessness ends. Once the parabola ends, polarity on the capacitor will be reversed and the dust will be recollected on the 'thumper' in preparation for the next parabola. Dust collection will be aided by circulating ionized gas through the chamber. As the dust interacts with itself, the video camera on the top part of the apparatus will record the qualitative movements of the dust to determine whether it clumps or quickly disperses and what particle trajectories are. A low energy LED will be used to illuminate the particles for video observation, without charging the particles. Our team is certain that we will receive valuable data from these measurements because of the success of Get Away Special team reliable video data collection from ten years ago (Wright).

An electrometer will be connected to the foil of the capacitor, the grounded wire, and the high voltage supply (for calibration) and record the current as a function of time during each parabola. Sub-picoampere currents will be measured using custom built circuits. The currents will be recorded through analog input channels at 100 Hz rates using a USB data acquisition card (McDAQ Model USB-3100) connected to a PC-based laptop computer running Labview 8 software. The data acquisition card, computer, and software are on loan for other USU research

groups. The acquisition system will also control system voltages, air circulation valves, monitor temperature, and record light intensity using a photodiode.

Test Matrix

Table 2 shows the ways that our team intends on varying each test during one day of flight and will be repeated the second day. Each successive parabola of the C-9 will result in a change in the voltage supplied to the capacitor with the light unfiltered, and then again with the filter in place.

Need for Microgravity

There are many issues associated with the experiment that would necessitate the use of microgravity conditions. The most important issue associated with our experiment is its purpose. Our purpose in studying the effect of charging the silicon dust was motivated, as mentioned previously, by our understanding that when we landed on the Moon, there were problems with charged lunar dust coating the electric circuitry of the Lunar Module. In order for our experiment to have the greatest benefit, it is necessary to study the behavior of our charged silicon dust in an environment with gravity less than that of Earth's gravity.

As the purpose of the experiment is to study the effect of the charged silicon particles, not only would performing the experiment in a place of lessened gravity give more understanding in the context of lunar problem, but a more definitive understanding of the general behavior of these charged particles. By reducing the force of gravity we would also be reducing the variables that would affect the behavior of the silicon particles as they become charged and interact, and therefore dominantly electrostatic interactions would be possible to observe.

The electric field necessary to balance the force of gravity when the particle has lost one electron is:

$$E_q = \frac{G \cdot M_E \cdot m}{R_E^2}$$
 (Eq. 3)

where E is the electric field needed, R_E is the radius of the earth, M_E is the mass of the earth and m is the mass of the particle. The following table shows the various voltages needed to balance the force of the gravity in each environment (from correspondence with Eric Neumann at NASA, the C-9 experiences 0.01 times the force of gravity on the surface of the earth).

The last issue that would necessitate a micro-gravity environment is that of voltage. Because the silica particles would be subjected to the full force of gravity on earth it would require in excess of 18 kV of electricity to create the necessary electric field to cause the silicon particle to be drawn to one wall of the capacitor. By reducing the force of gravity on our particle we estimate that it would require less than 200 V to create a sufficient electric field to cause our particle to be drawn to the wall of the capacitor. By reducing the voltage in our circuit we can thus create a safer environment under which to perform our experiment.

Table 3. Voltages and Electric Fields necessary to balance force of gravity

	Force of Gravity (N)	Necessary 'E' Field (N/C)	Voltage Needed (V)
Normal Gravity	7.53E-14	4.51E+05	1.84E+04
Micro Gravity	7.53E-16	4.51E+03	1.84E+02
Lunar Gravity	1.26E-14	7.52E+04	3.07E+03
Martian Gravity	2.83E-14	1.70E+05	6.92E+03

Particle Radius (microns): 9
Particle Mass (kg): 7.7E-15
Capacitor Radius (m): 0.0508

In reference to earlier experiments conducted concerning charged particles, gravity is a confounding factor in determining the interaction of the particles on the charge alone. Millikan started in a good direction with invaluable information. Our team intends to take it one step further and not only see the electrical effects on charged particles but also be able to determine the photoelectric effect on particles unaffiliated with earth's gravity. Gravity is an influencing factor in earth based experiments unless a state of free fall can be achieved. If this is possible then our knowledge could be better used in a non-earth based setting.

Justification for Follow-Up Flight

Not applicable to this project.

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Experiment Safety Evaluation

Flight Manifest:

Sarah Isert: No RGSFOP experience Vicki Ragsdale: No RGSFOP experience Lance Petersen: No RGSFOP experience Dean Lanier: No RGSFOP experience (Alt) Alex Wright: No RGSFOP experience

Experiment Description/Background

This experiment is designed to research the effect of charging due to ultraviolet light on a lunar dust simulant. The simulant will be placed in an opaque coaxial capacitor and exposed to ultraviolet light. Through the photoelectric effect, the dust will become positively charged. The electric field generated by the coaxial capacitor will push the dust to the sides of the chamber, where the current will be measured by a picoammeter. Video footage of the experiment will also be taken through a video camera attached to the lid of the capacitor. This experiment is not a reflight.

Equipment Description

The experiment will be made up of one computer, an ionizing hairdryer, and three to four canisters that will each contain a coaxial capacitor, a light source a low energy LED, a dust sample, a USB missile launcher ('thumper'), a camera, a photo sensor, a picoammeter, and possibly nitrogen circulation tubes. When the airplane enters the free-fall portion of the parabola, the light source will be turned on and a voltage difference placed over the capacitor. The dust particles, which will have fallen to the bottom of the tube during the 2G portion of flight, will be pushed into the air via the 'thumper.' The light source will charge up the dust particles, which will be attracted to the side of the canister by the electric field. The resulting current will be measured by the picoammeter. When the aircraft exits the free-fall portion of flight, the capacitor will be discharged and the dust will be de-ionized through the use of the ionizing hairdryer. The picoammeters and the cameras will be connected to the computers so data can be easily connected and stored. After each flight, or possibly between parabolas, the data will be stored on a USB drive or CD as a backup to the computer file.

Structural Design

The tubes containing the capacitor will be made out of ABS. Each tube will be placed in a rack that will hold up to four of these tubes and the requisite support equipment. The structural design of this rack has not been finalized; however, it will be able to withstand the expected structural loads. The components will be attached to the experiment's frame via a hinged cradle (similar to that used on the Meade DS 2000 tripod series). This will prevent movement in all directions. The frame is expected to be attached to the aircraft's floor with bolts. A block diagram of the structure and electronics is below (Fig. 4).

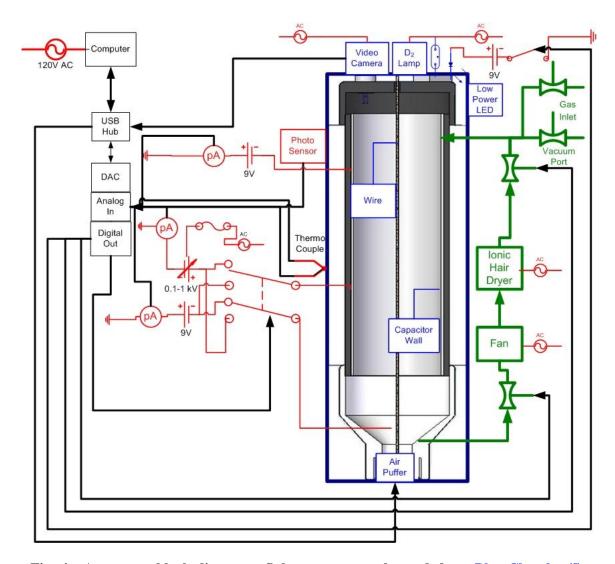


Fig. 4. Apparatus block diagram. Subsystems are color coded as: Blue-Chamber/Structure, Red-Electronics, Green-Gas System, Black--Data/Computer System.

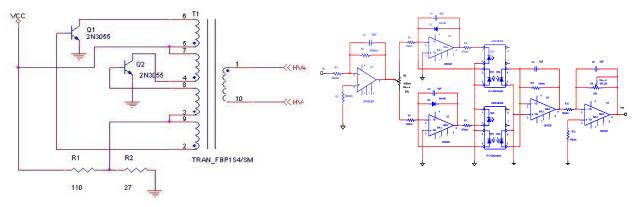


Fig. 5 – AC/DC high voltage converter schematic. **Fig. 6** – Custom picoammeter schematic (Thomson).

Table 4. Estimated Power Requirements

Component	Quantity	Power (Watts)
Ionic Hair Dryer (no heat)	1	20 W
Fan	4	40 W
D ₂ Lamp	4	40 W
Video Camera	4	60W
Air Pulsar	4	20 W
High Voltage Supply	4	80 W
Computer	1	40 W
Cooling Fan	1	20 W
Total		320 W

Electrical System

There are five major components in the electrical system: the coaxial capacitor, the light source, the camera, the picoammeter, and the computer. The computer and the light source will run off 120 V AC power. The capacitor will also run off of 120 V AC power; however, a step-up AC/DC converter (Fig. 5) will be needed to raise the potential difference to the requisite 1000 V. At the same time, the current will be lowered to below dangerous levels. The picoammeter (Fig. 6) runs off of a 9 V battery. There will be a kill-switch to terminate the electrical system should there be a dangerous malfunction. Control of all switches and operations will be by a program previously created in LabView and stored on the laptop. Connection to aircraft 120 V, 60 Hz AC power is requested. AC power requirements are expected to be ~320 W (see Table 4).

Pressure/Vacuum System

There will be no pressure/vacuum system used on this flight. The pressure of the dry N_2 in the tubes will be adjusted to match the cabin pressure by means of a release valve, but because we have not finalized how circulate nitrogen through the cylinders, this data will be included in the formal TEDP submitted after the proposal has been accepted.

Laser System

No lasers will be used on this flight.

Crew Assistance Requirements

No special duties will be requested of the Flight Crew in assisting with the experiment operation. We will, of course, request help with items such as hooking up our experiment to the aircraft's power system.

Institutional Review Board

This is not an experiment involving human test subjects, animal test subjects, and/or biological substances.

Hazard Analysis

Hazard Analysis PROBLEM	PREVENTION
The experiment containers could knock against something and shatter, throwing shards of plastic and bits of dust throughout the cabin.	The containers will be in a frame that is attached to the floor, preventing them from floating around the cabin. All loose objects will be secured, and people will be advised to be cautious around the experiment. Also, of course, the tubes will be built out of sturdy, shatterproof plastic that can handle casual and not-so-causal bumps.
The Latex tubes connected to the USB 'thumper' could tear, releasing dust into the cabin and rendering the experiment inoperative.	We will be flying multiple test cylinders so the loss of one test tube will not necessitate halting the experiment. The design of the cylinder test rack has not been finalized; however, one of the designs we are considering has the cylinders contained completely in a box, so if there is tube rupture, the dust will be fully contained. Whatever design we decided upon will ensure that no dust will enter the cabin in the event of a rupture.
We will be using ultraviolet light in the experiment, which can be hazardous to human beings.	When the light is turned on, it will be fully contained in the test cell, which will be built out of a material that is opaque to ultraviolet light. To ensure that no one is accidentally exposed to the light, a kill switch will be employed that makes it physically impossible for the light to be on while the test cell is open. We will use a photodiode to see whether or not the light is operating, and in the highly unlikely event of a test cell rupture, a kill switch will be wired into the system that will shut off the light immediately.
The experiment and the data collection system will be connected by cords. If people accidentally get caught on the cords they could rip them out of the experiment.	The data collection system will be right by the experiment in the base dock with the electronics systems so there are no cords hanging across the cabin. Any cords, wires, or tubing will be attached to the experiment structure so they can't drift up in the periods of free-fall.
	The capacitor will be stored discharged between flights, and will not be charged until the experiment begins. Between data runs the

The experiment involves a capacitor. Capacitors can be very dangerous if they are not dealt with properly. Some risks involve rapid discharging of the capacitor. capacitor will be discharged using a discharge stick. When the capacitor is charged, the lid will remain on the experiment, preventing anyone from accidentally running into the capacitor and receiving a shock. Also because air is mostly made up of nitrogen and the dielectric strength of air is 3 MV/m (Boylestead), we are not concerned about the capacitor arching across its terminals.

We are considering charging the test tubes with nitrogen. If we end up doing so, there may be problems such as over-pressurization causing test cell rupture, feed lines becoming disconnected, and other problems associated with carrying tanks of nitrogen around.

The nitrogen will be carefully metered to prevent too much from entering the test cell at once. In addition to that, there will be an overflow valve on the cell that will release nitrogen if it exceeds the pressure level of the plane. Feed lines will be securely attached, and if one does become detached each cell will have a valve that enables us to turn off the nitrogen to that cell. If the line does become detached there is a slight possibility that some dust might escape from the cell. Details have not been worked out how the dust would be contained in this eventuality; however, the feed lines for the nitrogen would be located on the side of the experiment so they would be easily accessible in the event that they come loose. A patch (similar to a bike tube patch) would be placed over the hole for the remainder of the flight. To minimize the hazards of carrying around large tanks of nitrogen the cells would be charged before they left the ground, and only a small bottle of nitrogen would be used on the aircraft.

There may be problems with the electrical system, including the picoammeter and the capacitor.

Each part of the experiment will be thoroughly tested before flight week, and then again before each flight. These tests will include but are not limited to testing connections, voltage and current levels, and general operations of the system. Safeguards such as fuses and current regulating resistors will be built into the system, and there will be a general kill switch that will immediately cut off power to the system should the need arise.

Tool Requirements

Currently, the only tool necessary seems to be a wrench (type undetermined but that data will be included in the formal TEDP submitted after the proposal is accepted.) to attach the experiment to the floor of the aircraft. Other basic tools may be needed to make small adjustments to the structure, but that has not been determined at this time.

Ground Support Requirements

We will be requesting the use of ground power from RGO and, perhaps, the storage of pressurized nitrogen. As small changes are made to the experiment other services may be needed, but as of yet these are the only ones necessary.

Hazardous Materials

We will not be using hazardous materials for this project.

Procedures

GROUND OPERATIONS:

Check electrical circuits, data collection system, and 'thumper' assembly for any anomalies. Also check to make sure ultraviolet light source is operational. Verify there is dust in every cylinder. Seal cylinder.

PRE-FLIGHT:

Install experiment on board aircraft. Do a final check after the electrical system is hooked up to make sure the kill switches work properly.

IN FLIGHT:

Microgravity: Charge capacitor and turn on UV light. Turn on picoammeter and data collection system. Use the thumper assembly to distribute dust throughout cylinder. Collect and record data

2-G: Discharge capacitor and dust. Check systems to make sure they are still whole and operational. Save data.

POST FLIGHT: Save a backup copy of the data. Check all systems to make sure they are still operational. Go over data and see if there is anything that piques our interest enough for us to focus on in during the next flight.

Outreach Plan

Direction and Purpose

The Microgravity Research Team (MRT), formerly GAS team, has a legacy of over 20 years of strong educational outreach. Thus far, the most effective method has been through hands-on learning, social interaction, and the creation of a mentoring program.

Primary and Secondary School Presentations

We intend to outreach to the large spectrum of students from kindergarten through high school because the sooner students become aware of careers in science and engineering, the more apt they will be to pursue said careers. Presentations to high school science classes during the spring of 2009 are scheduled to take place at the high schools listed below, and will compliment the efforts of the teachers as they teach the basics of the photoelectric effect. Additional contacts will be made with more than 250 Science, Technology, Engineering, and Mathematics (STEM) teachers attending USU Physics Day at Lagoon. Presentations to primary schools are still being approved by administration and will include many visual presentations and videos. However, previous projects by the GAS team, such as comparing popcorn that has been in space to earthbound popcorn, have established relationships with Nibley Elementary School and other schools, and we are sure that our team will be allowed to present to the children.

The following is a list of teachers with their respective high schools that have agreed to let MRT come into their classroom and show a demonstration of the photoelectric effect. These presentations will take place during the spring in order to compliment the physics curriculum when most classes will cover the photoelectric effect. Through these presentations we will involve students directly with data analysis.

A secondary goal is to build long-term relationships as mentors with these high school students. During the presentations, the members of the team will be able to split the class into groups and talk with them about their future plans and what they want to do one day, acting as a mentor in their college deciding process. After this initial meeting, email addresses will be exchanged and the mentor will keep in touch with these students as they make their decisions about their future. Since the team members have been through this process and have a couple years of college of experience behind them, they will be able to give applicable advice.

Table 5. Secondary Teachers involved in MRT Outreach

Teacher	High School
Ivan Iucker	Cyprus High
Dr. Stephanie Atherton	Judge Memorial Catholic High
Jay Harte	St. Joseph's Catholic High
Scotti Hansen	American Heritage (primary and secondary)
Greg Nielsen	Logan High School
Stephanie Kawamura	InTech Collegiate High

Clarke Planetarium Display

The Clarke Planetarium in Salt Lake City, Utah, has agreed to let MRT create a display about the photoelectric effect to augment their plans to develop a display on charging of lunar dust through NASA Gateway Science Consortium. Members from the team will be able to talk with the patrons about the basics of the photoelectric effect and why it is an important consideration for Moon inhabitation. The display will include a poster about the team and the basics of the photoelectric effect. It will also include a demonstration of how light can charge a plate of copper as well as mock ups of the proposed "Vomit Comet" experiment. With 2009 being the centennial anniversary of Millikan's Oil Drop experiment and his further work on the photoelectric effect, our presentation will help to inform students and guests about the ramifications of this research. This will allow the team members to make connections with Utah residents and spread the word about NASA's and Utah State University's research opportunities.

Expanding Your Horizons

EYH (http://www.expandingyourhorizons.org/) is a day long event sponsored by ATK Space Systems for girls in grades 6-9 to attend workshops lead by various groups. MRT will lead a workshop focused on the Moon. The negative effects of lunar dust will be emphasized. As a demonstration, the girls will be able to throw "meteorites" simulated, by small rocks, into "lunar dust" simulated with flour. The girls will be able to observe how messy moon dust can be. Demonstrations used at the Clarke Planetarium will also be used here to illustrate charging effects.

Physics Day

For 20 years, MRT has been a part of the USU Physics Day at the Lagoon amusement park in Farmington, Utah. Physics Day is an annual event for more than 6,500 students in junior high and high school which allows students to be introduced to how physics can be really fun. Over the yeas, more than 100,000 secondary students and teachers from 6 states (Utah, Idaho, Wyoming, Nevada, Colorado, and New Mexico) have participated. MRT displays provide opportunities for direct interaction with the students. Past displays have featured MRT/GAS payloads and joint experiments with high schools, the current MISSE-6 experiment on the ISS, and the future USU CubeSat project. The planned dust charging display is a natural outgrowth and extension of these displays. Annual hands on activities at Physics Day run by MRT, like launching paper rockets, are models for proposed MRT outreach student activities.

Aside from associations with K-12 students and partnerships with various groups, MRT will discriminate the results of the experiment and recognition of NASA's role to the general public through various outlets.

Project Website

The Internet is the most efficient way to spread the word about MRT and the experiment to not only USU students but the entire world. Therefore, a website has been created for this

experiment by the MRT and the sub-team the Applied Flight Research Group (AFRG) at: http://www.mrt.usu.edu/afrg.

The following is the planned basic structure of the website:

- Title Page: Short synopsis of what the experiment is and any recent updates.
- Experiment Design: Lengthy discussion of the experiment design and links to related articles.
- Experimental Results: A summary and discussion of measured results, including graphical and video formats.
- Outreach Page: A calendar of team visits to schools and other outreach activities.
- Fundraising and Thank You Page: Means of donating to the MRT acknowledgements of sponsor contributions, including links.

USU Admission Recruiting

The MRT has been featured prominently by the USU Admission Office in recruiting materials, including posters, news articles, websites, and an award winning video (http://www.usu.edu/multimedia/thinkspace/). They plan to feature the MRT "Vomit Comet" experiment in future features.

University and Local Press Plan

MaryAnn Muffuletto is responsible for public relations and marketing in Utah State University's College of Science. With her as liaison, our team has access to local and statewide newspapers for distribution and publicity of our team and interaction with local schools and private companies. Some of these outlets include the USU newspaper, the Statesmen; the Logan metropolitan area newspaper, The Herald Journal; flyers; making a small presentation at the beginning of classes; announcement on the USU radio. However our biggest advocates will be our partnerships with the Society of Physics Students, the Physics Department, Engineering Council, and Society of Women Engineers. MaryAnn has been instrumental in previous recognition of our team's CubeSat project to commemorate the 50th anniversary of Sputnik, the MISSE-6 project currently on the International Space Station, and the GAS teams' previous Vomit Comet experiment and shuttle payloads.

Small Satellite Conference

The AIAA /USU Small Satellite Conference is held every August in Logan, Utah, and sponsored by the USU Space Dynamics Lab. This conference attracts both professional engineers and engineering students. MRT will present results here as they have for past projects. It will serve as a way of getting the word about the RGSFOP out to other universities that are in attendance.

MRT has routinely presented results from its research activities at USU Student Showcase, Utah Research on the Hill, National Council for Undergraduate Research, NASA Rocky Mountain Space Grant Consortium Annual Student Forum, and American Physical Society Four Corners Regional meetings.

Partnerships

USU Space Dynamics Lab (SDL)

SDL is currently co-sponsor of USU/MRT CubeSat work and provides mentoring by professional engineers and scientists for college students. A joint venture between MRT and SDL is MISSE-6, an experiment currently on the ISS. SDL is a source of funding for MRT's "Vomit Comet" experiment and will aid in publicity for MRT's outreach and results.

ATK Space Systems

Gil Moore, founder of the USU GAS team, was vice president of Thiokol prior to the merging with ATK. MRT still retains ties with ATK by means of alumni, scholarships, and Dr. Moore (who serves on the faculty of USU's Department of Physics). These relationships provide opportunities for undergraduate students to network with professionals in their respective fields and publicity for MRT.

Rocky Mountain Space Grant Consortium (RMSGC)

The RMSGC acts as sponsor for MRT, the team's experiments, and research fellowships for undergraduates. It also aids in inter-collegiate collaboration with other universities including MRT's partnership with Weber State University to test aerospace components via high altitude balloon. MRT will present at the annual Rocky Mountain Space Grant Consortium Student Research Seminar.

Department of Physics

Although MRT is currently composed mostly of engineering students, the Department of Physics is one of the biggest advocates for the team and has been the MRT sponsor for over 20 years. With this connection, the team is able to attend Physics Day at Lagoon and be included in the College of Science's monthly newsletter that is mailed to students and alumni.

Associated Students of Utah State University (ASUSU)

ASUSU is responsible for all the new student orientations and helping new students find their place at USU. Having this partnership will allow the team to make presentations to young potential students and show them how exciting physics and engineering can be. ASUSU also provides further support for MRT's recruiting efforts.

On-campus Groups

E-Council is the engineering student government for the College of Engineering. MRT will present their display at Engineering Week sponsored by E-Council, to help promote engineering education and outreach.

MRT will also participate in discussions with a very active Society of Women Engineers (SWE) and Society of Physics Students (SPS) and will share their photo-yield display to share what the team is doing and what the experiment is about rather than convincing them to become interested in the fields of engineering and physics. SWE is a nonprofit organization who provides a source of support and encouragement for women in engineering.

Administrative Requirements

Institution's Letter of Endorsement

Institution's Letter of Endorsement can be found following this section (paper copy only).

Statement of Supervising Faculty

Supervising Faculty Statement follows our institution's Letter of Endorsement (paper copy only).

Funding/Budget Statement

The following is a list of anticipated expenses associated with this experiment including apparatus equipment, transportation of team and experiment to Houston, and accommodations while in Houston.

Table 6. Budget Summary

Experiment Equipment	Quantity	Cost
Silicon Dioxide (BK7) Spheres, 18 µm from Sorbent Tech	100 g	\$75.00
Silicon Dioxide (BK7) Spheres, 60 µm from Sorbent Tech	100 g	\$75.00
Silicon Dioxide (BK7) Spheres, 2 µm from Sorbent Tech	100 g	\$75.00
Black PVC		
- Pipe 4"x5'	5 ft	\$9.97
- End cap	6	\$35.10
Metal – 5"x60' Galv. Pipe (Faraday cage)	3	\$21.84
UV Lamp (from Secure Air 1200)	3	\$250
Picoammeter	9	\$1,000
High Voltage Converter	3	\$300
Digital Video Camera	3	\$700
Laptop Computer	1	Free use from
		USU
USB Data Acquisition Card Interface		Free use from
		USU
Shipping Costs (Experiment)		\$250
Dream Cheeky USB Missile launcher ('thumper')	3	\$100
Edmund Optics UV Longpass filters	6	\$101.40
TECHSPEC® Shortpass filters	3	\$210
Ionic Hair dryer (Conair Infiniti Nano Silver Tourmaline)	1	\$55
Subtotal		\$3,258.31
Travel Expenses		
Transportation to/from Houston (Airfare)	N/A	\$1,401.00
Accommodations in Houston (2 hotel rooms for 10 days)		\$1,100
Food (\$32 * 10days * 6 people)		\$1,920
Vehicle Rental		\$318.39
Subtotal		\$4,739.39
Total		\$7,997.70

If there is sufficient funding for a fourth canister, the cost will increase by about \$1,000.

The Microgravity Research Team has a several thousand dollar budget to help fund its experiments, but additional funding is possible though Rocky Mountain NASA Space Grant Consortium, the Utah State University Department of Mechanical Engineering, the USU Space Dynamics Laboratory, ATK Space Systems, and several local private companies. Our team will also apply for Utah State University's Undergraduate Research and Creative Opportunities grant in the spring, and if received, will contribute \$1,000 to funding our project. We are working with Utah State University's Development office to contact former alumni of our team to help increase funds to continue to fund opportunities for undergraduate students to participate in research. We hope that this will also continue to solidify relationships of our team members with K-12 students as well as mentors in the industries we hope to enter.

Institutional Animal Care and Use Committee (IACUC)

Not applicable to this project.

Parental Consent Forms

Not applicable to this project.