

Binary Orbital Motion of Electrically Charged Spheres
Final Report



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—1848—

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Abstract

The similar mathematical forms of Coulomb's Law of Electrostatics and Newton's Law of Gravitation suggest that two oppositely charged spheres should be able to move in a binary orbit about their center of mass using only the electric force as the force of attraction. To test this idea, we attempted to produce binary orbits between oppositely charged graphite coated Styrofoam spheres. We succeeded in our goal, achieving multiple successful orbits. Prior to our experiment, orbits of this nature had never been achieved. Because the force of gravity on the spheres is much greater than the electric force between the spheres, a weightless environment is necessary to have orbits. We were able to access this environment through NASA's Microgravity University program.

Introduction

NASA's Microgravity University program allows undergraduate student teams to conduct an experiment aboard a modified C-9B aircraft that creates a weightless environment. The student microgravity team, the Rhodes Binary Orbit Team (RhoBOT), submitted a proposal to NASA on October 30, 2007 that was accepted by Microgravity University. The spring semester and part of the summer of 2008 was spent designing our experimental apparatus and performing ground based experiments. In July 2008 we traveled to the Johnson Space Center in Houston, TX, to conduct the experiment. The 2008 fall semester has been spent analyzing the data from the flights. We plan to publish our results in a scientific journal such as the American Journal of Physics.

Test Objective

The objective of this experiment was to establish a purely electrostatic binary orbit between two oppositely charged graphite coated Styrofoam spheres. The spheres had a mass of 1.6 grams, radius of 1.5 cm and were charged to a surface voltage of +/- 20 kV. Initially the spheres were separated by a center to center distance of 15 cm. Once charged, the spheres were launched in opposite directions (perpendicular to the line adjoining their centers). A successful orbital attempt resulted in the two spheres orbiting one another about their center of mass.

This experiment was motivated by the mathematical similarities between Coulomb's Law of Electrostatics and Newton's Law of Gravitation². These are given in Equations 1 and 2, respectively:

$$(1) \quad F_E = \frac{q_1 q_2}{4\pi\epsilon_0 r^2}$$

$$(2) \quad F_G = \frac{Gm_1 m_2}{r^2}$$

These equations suggest that oppositely electrically charged spheres should be able to move in a binary orbit about their center of mass in which the attractive force between the spheres is the electric force. This is analogous to the orbital motion of a binary star system in which gravity is the attractive force between the orbiting bodies³.

Experimental Progress

Beginning in January 2008, our team worked on designing and fabricating a specialized apparatus to charge and launch the orbiting spheres. We constructed an apparatus consisting of a wooden frame measuring 55.5 in. x 21 in x 55.5 in, two launching mechanisms, and two charging mechanisms. The sphere launching mechanism consisted of a polypropylene frame measuring 7.3 in x 0.98 in x 3.9 in, bicycle brake cables with housing, and a lever. A launching mechanism is shown in Figure 1.

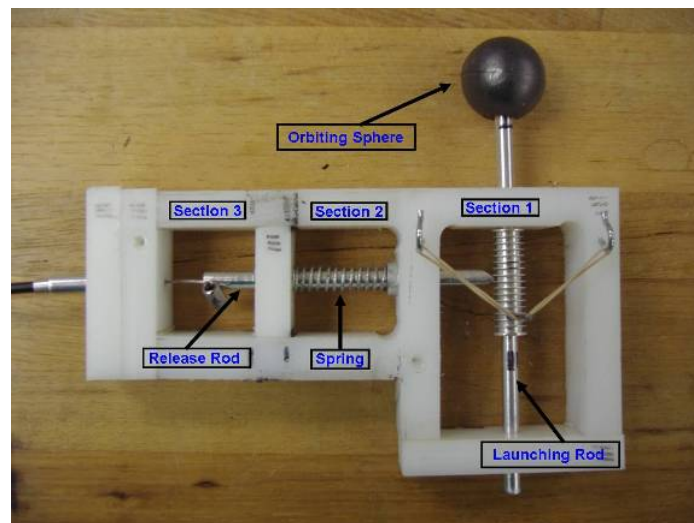


Figure 1: Fully Constructed Launching Mechanism

A stretched rubber band was used to accelerate the launching rod to launch a sphere placed on the end of the launching rod. There were 7 grooves in the launching rod allowing for

the testing of 7 different launch speeds. To hold the rod in place before launching the sphere, a release rod measuring 4.0 in passed through sections 1, 2, and 3, perpendicular to the launching rod. It has a wedge shaped tip that allows it to fit into the grooves machined into the launching rod. A spring was located in section 2, which held the release rod in one of the grooves. The launcher was actuated using a bicycle brake cable to pull the release rod from the groove. The bicycle brake cables were connected to both launching mechanisms and connected to a single bicycle brake lever via a cable splitter so that both launchers could be actuated at the same time. A hole was drilled in the sphere in which the metal launching rod was inserted. Each launching mechanism was attached to a moveable platform so that it could be retracted out of the way after the spheres were launched. A high voltage power supply with custom fabricated electrodes was used to charge the spheres.

The charging mechanisms were located on adjustable platforms secured to the main frame of the apparatus. The charging mechanisms consisted of electrodes from the high voltage power supply which were mounted to an articulated arm with dimensions 11 x 1.5 x 0.75 in. Positioning of the articulated arms was assisted by a damped self-closing hinge mechanism. When the sphere chargers were in the charging position, they were held by a mechanical latch that was attached to the moveable launch platforms. After the spheres were charged the latches were released, allowing the sphere chargers to retract. The completed experimental apparatus is shown in Figure 2.

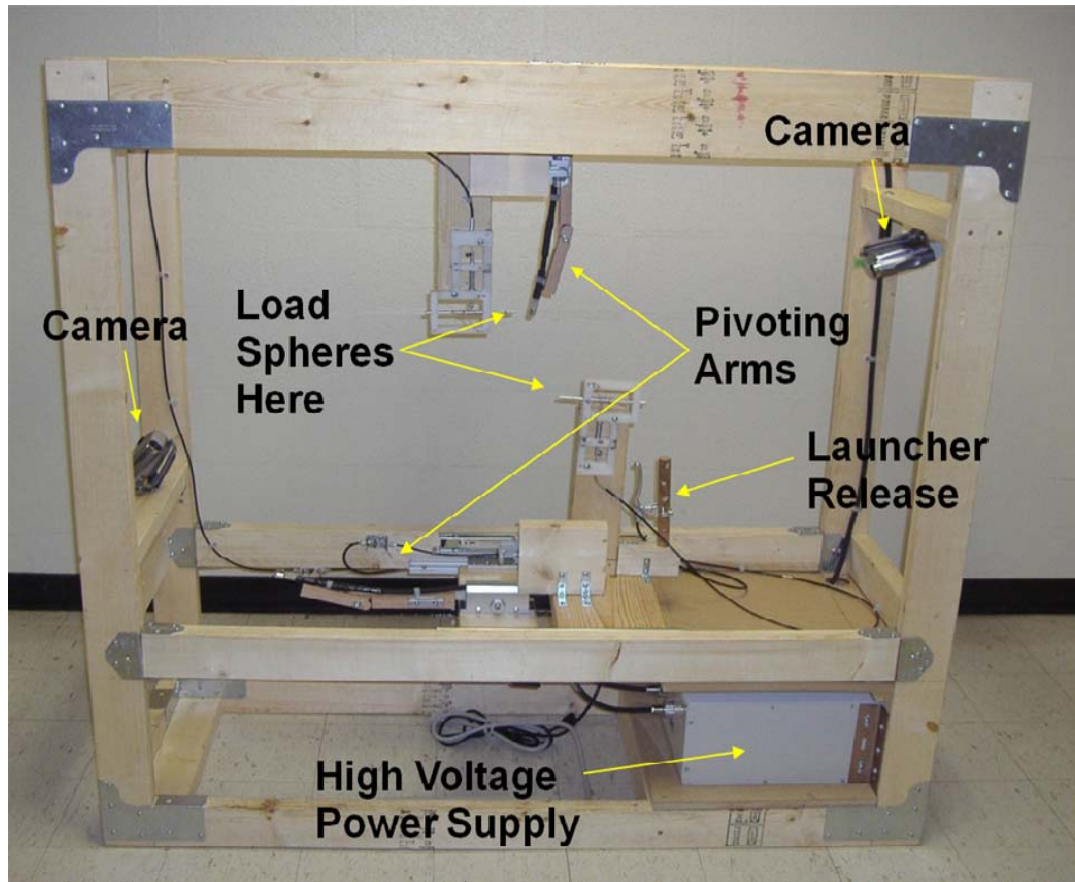


Figure 2: Completed Experimental Apparatus

We used an orbital separation of 15 cm between the spheres. The two orbiting spheres were graphite coated Styrofoam balls ($m = 1.6$ grams, $R = 1.5$ cm). The spheres were launched with an initial velocity of approximately 15 cm/s and were charged to a surface voltage of +/- 20 kV. Data were collected by analyzing the video footage of the orbits.

Additional data were gathered using a Vernier LabQuest and Wireless Dynamics Sensor System equipped with sensors to measure x-y-z acceleration, air pressure, humidity, temperature, and oxygen concentration. Data gathered with these sensors characterizes the in-flight environment and may be published to aid in the development of future microgravity experiments.

Results and Future Work

During the two flights, we achieved 10 successful binary orbits. A successful orbit was defined as at least $\frac{1}{2}$ of a revolution. An example of a successful orbit is posted on YouTube (keywords: Rhodes, binary). We are in the process of analyzing the video footage from these orbits. Up to 30 launch attempts will be analyzed to better understand the force acting between the spheres. We plan to submit our results for publication in a scientific journal. We were successful in our goal of achieving the world's first purely electrostatic binary orbit.

As part of the Microgravity University program, we conducted substantial educational outreach to the Memphis community. We interacted with over 400 students at two local elementary schools and two local high schools.

We have presented (and plan to present) the findings of our research at the following scientific meetings:

- Sigma Pi Sigma Congress, November 6-8, 2008
- American Association of Physics Teachers, February 16-20, 2009
- Society of Physics Students Zone 10 meeting, February 27-28, 2009
- American Physical Society March meeting, March 16-20, 2009
- Council on Undergraduate Research, Posters on the Hill, April 27, 2009



Figure 3: Photograph of student team at the NASA Microgravity University facility

References

1. Banerjee, S., K. Andring, D. Campbell, J. Janeski, D. Keedy, S. Quinn and B. Hoffmeister, "Orbital motion of electrically charged spheres in microgravity," The Physics Teacher (in press).
2. Griffiths, David J. Introduction to Electrodynamics, 2nd ed. Upper Saddle River: Prentice Hall, 1989.
3. Fowles, Grant R., and George L. Cassidy, Analytical Mechanics, 7th ed. Pacific Grove: Brooks Cole, 2005.

Budget

Microgravity University provided no funding for the selected teams.

Sensor Package

- Humidity/Temperature/Dew Point Sensor -\$70
- Absolute Pressure Sensor- \$90
- Oxygen Gas Sensor- \$190

Supplies

- Teflon Needles (3 boxes of 50) - \$145
- Graphite Coated Styrofoam Spheres (99 Spheres)- \$95
- Lumber- \$50
- Polypropylene- \$50
- Plexiglas- \$55
- High Voltage Power Supply charging cables- \$700
- Precision Track Roller Guide Blocks- \$500
- T-Slot Rails- \$35
- Vinyl tubing and connectors for pneumatic launch- \$20

Total Requested Amount- \$2000

Actual Expenditures to Date

Sensor Package

- Wireless Dynamics Sensor System-\$249.00
- O2 Gas Sensor - \$188.00
- Relative Humidity Sensor-\$69.00
- Stainless Steel Temperature Probe-\$29.00
- Barometer-\$69.00

Supplies

- Teflon Needles (3 boxes of 50)- \$165.14
- Graphite Coated Styrofoam Spheres (99 Spheres)-\$95.00
- Polypropylene- We received a donation from a Memphis supplier
- Plexiglas- \$54.38
- High Voltage Power Supply charging cables-\$640.00
- Precision Track Roller Guide Blocks- \$492.54
- T-Slot Rails- \$32.65
- Vinyl tubing and connectors for pneumatic launch – We did not pursue this method

Total Spent on Requested Budget Items-\$2083.71