SOCIETY OF PHYSICS STUDENTS

An organization of the American Institute of Physics

SPS Chapter Research Award Interim Report

Project Title	Cavendish Experiment
Name of School	University of Central Florida
SPS Chapter Number	1076
Total Amount Awarded	$2,000.00
Project Leader	Brian C. Ferrari

Abstract

To enhance the measurement of the Gravitational constant we the Society of Physics Students at UCF will implement a high linearity silicon-based position sensitive detector. Allowing for more accurate measurements across a larger range of displacements, verifying the position-dependence initially suggested by D. R. Long [Nature 260, 417 (1976)].

Statement of Activity

Interim Assessment

- Research question
- Einstein's General Relativity has provided a phenomenal model for addressing gravitation, the unfortunate issue with his theory is the lack of unification with other physics theories. Several scientists have presented various hypothesis for this possible breakdown of relativity with conjoining it with other theories. Our experiment will attempt to verify or disprove these hypotheses. Through the implementation of a high linearity 1-dimensional silicon-based Position Sensitive Detector (PSD) we can yield measurements of the gravitational constant across a large range of initial separations. This large range can be used to attempt to verify the position-dependence of the gravitational constant initially suggested by D. R. Long [Nature 260, 417 (1976)]. Along with the PSD our technique includes piezoelectric polymer-based vibration

sensors which will allow us to conduct the experiment several times for one positions and identify the noise in our system. Once noise is identified we aim to produce an algorithm or program to convert vibrational data into PSD data allowing for us to remove the noise from our data before analyzing our data. If removal of noise from our data is not possible we can still use this data to identify the instance in which our data has the fewest sources of noise. This technique could prove to be a powerful technique for minimizing error in future Gravitational constant measurements. In conclusion, our research aims to identify any variations in the Gravitational constant (ie: variations in the gravitational force of attraction) as well as attempt to provide a novel noise reducing technique.

- <u>Brief description of project</u>
- The project so far has required 3d models to be made in solid works as well as machining of several parts. We have also been reading several published papers on the topic of gravitational constant measurements. This has lead us to expand the aim of the research to not only a more accurate measurement of the gravitational constant but to determine the validity of the hypothesis on the position dependence of the gravitational constant. Reading publications has lead us to change the setup of our research experiment, we will no longer use a dumbbell system as the torsion bar since that leaves several possible sources of error instead we will use a rectangular plate of polished silver allowing us to avoid errors in the measurement of the mass of the sphere, mirror and rod. The laser beam will reflect off the rectangular surface directly, which is why polished silver has been chosen, it allows for maximum reflectance of our wavelength of light. We have also read a significant amount about vibration sensors and decided to add piezoelectric polymer-based vibration sensors along the apparatus that holds the torsion plate. We will use the vibration sensors to measure the vibrational noise that is affecting our experiment then we can remove the noise from our measurements allowing for increased accuracy. We will also be replacing the larger mass spheres with cylindrical spheres since they are easier to make therefore cheaper, allowing monetary resources to be allocated towards more precise measurement devices which hold priority in the experiment. The cheaper cylindrical masses also allow us to purchase different masses to allow for precise measurements to be made for each different hypothesis being tested in our experiment. The cylindrical mass also allows for easier measurements to be made, minimizing the uncertainties within our experiment. Our research aim has also been broadened to verification of the position dependence of the gravitational constant.

- <u>Progress on research goals</u>
- A 3D model was created in SolidWorks. The apparatus that holds the torsion plate has been built, along with a dumbbell system which proved to be substantially more difficult to work with than previously expected. The system requires precise balance to work and any vibrations cause the entire system to become unstable, in an effort to remove this large source of error in our experiment we searched alternative methods. In our search we discovered a technique where instead of a torsion bar a flat plate was used by J.H. Gundlach and S.M. Merkowitz [APS, (2000)]. We have removed the torsion bar from our experiment and begun designing a method for attaching the flat plate, we are holding off attaching the appropriate polished silver plate until the experiment assembly has been finalized to prevent damage to it.

- <u>Any changes in the scope of project</u>
- The project has proven to be more complicated than it seemed due to the torsion bar's refusal to remain in a balanced equilibrium position. The torsion bar setup also raised several concerns with the vast amount of observational errors it brought to the experiment. Since the rotational moment

of inertia of bar is dependent on {mass of spheres, mass of rod, mass of mirror, distance from rotational axis to masses} it began to accumulate too many errors which would prevent our experiment from yielding any decent data. In an effort to correct these issues we replaced the rod with a flat piece of polished silver in our designs, currently we have been investigating our apparatuses ability to support similar pieces of aluminum in a balanced position and the results have shown significant improvement. Vibrational noise has also proven to be more a more intense problem than originally believed to be, for this we have adapted several vibration sensors into our design. Noise from "drafts" (air flow) have also proven more complicated than believed to be, so we have begun to develop a polycarbonate casing to cover the experiment, minimizing "draft" noise. Equipment compatibility has been another surprisingly intensive problem, since not all of our equipment runs on the same software we have had to learn new programs as well as develop our own forms of communication between devices.

- <u>Personnel</u>
- All the members of the group have continued to participate in the research activities with fluctuations on the amount of participation depending on course load and semester availability (some students return home during the summer and can't travel the large distance back to the university to participate). Students have assisted in the machining process, supervised by me (project leader) since I have years of machine shop experience. We have also had new students who were not part of the initial group formation participate, of those two are SPS members Zacchaeus Scheffer and Jamal Khayat. We also had the surprising pleasure of attracting the attention of a professor (one that is an SPS member, Christos Velissaris) who expressed interest in or experiment due to his curiosity of our technological implementations. He has not asked to participate but wishes to observe our experiment while supplying us with advice on the capabilities of these devices, since he is the instructor for the Scientific Instruments course his knowledge has proven to be a significant benefit to us. Majority of the students who expressed interest in collaborating with our project come from fields of data analytics, since our project will involve the collection of data from two sources and attempt to co-relate them. Finally, the technician in charge of all undergraduate lab course equipment has asked to be an observer, (while supplying advice as well) his involvement has also been great for the supplying of extra equipment.

- <u>SPS connection</u>
- With respect to SPS at UCF this project has helped to inspire more students to become more ambitious and seek out resources to help them better their academic or research abilities. This has also drummed up a lot of attention for the SPS at UCF chapter since collaborations have been made with students not originally members of our chapter. This has caused a rise in membership within the SPS chapter at UCF. Nationally this project will spread more awareness of the resources SPS has available to them. Since we plan on publishing our findings as well as presenting them at large conferences in the continental USA. These events will shine a light on the efforts SPS is making to advance undergraduate students, hopefully leading to more students taking the initiative to conduct their own research through SPS chapter research program.

Updated Background for Proposed Project

In 1972 Fujii attempted to produce a possible unification of gravitational theory with the weak and strong forces, he proposed that the gravitational force have Yukawa term due to the invariance of the particles that carry the force. This lead to his hypothesis that the gravitational potential between two masses be dependent on the Compton wavelength of the dilaton (an elementary particle). Then in 1976 D. R. Long analyzed the data collected by various experimental findings as well as his own experimental findings of the gravitational constant, where he developed a hypothesis that the inverse square law of gravitation breaks down at distances at the order of 0.1m. This hypothesis lead to several experimental tests along a range of initial separation positions of the order of 0.1m. Then in 1980 Spero et al. conducted a null mode experiment to test the inverse square law at a distance of the order of 0.1m, this experiment failed to find the variation hypothesized by Long. Shortly after Long published a paper explaining that the null mode test of the inverse square law is incapable of testing non-Newtonian invariances. Then in 1982 Cook & Chen conducted both a null mode and non-null mode experimental test of the inverse square law at the order of 0.1m, both of which failed to find the invariance of the inverse square law. Several more experiments have been done on the 0.1m order and lower attempting to find the invariance. Now in 2018 Haddock et el. implemented a pulsed neutron beam experiment to attempt to find the invariance at a nanometer range, their results revealed to have a substantial amount of unanticipated systematic error. There experimental results did provide sufficient data to get a Yukawa term to within 20%, hence 80% resolution. This is not sufficient to define the Yukawa term but was sufficient to determine the Yukawa term lies within the interval $\alpha(0.1\ \text{nm}) = (1.6\pm16.2)\times1022$ with 95% confidence. They conclude with plan for enhancing and producing more accurate results.

Description of Research - Methods, Design, and Procedures

1. **Design:** Our experiment consists on a symmetric apparatus that will suspend a tungsten wire from its center attached to a flat piece of polished silver. The polished silver will be suspended from its center and will be rectangular in shape, with a longer length than height allowing for the gravitational force applied to it to yield a larger torque. Two cylindrical tungsten-carbide rods will be placed on opposite sides of the polished silver (due to report length constraints figures have not been included refer to proposal diagrams). A near IR laser will be aimed at the center of the silver at a 30-degree angle from the surface of the polished silver. The reflected beam of the laser will be aimed at our PSD which will measure the displacement of the laser with resolution of 250nm. Along the base of the apparatus will be vibration damping pads, then vibration damping tape will coat the sides of the apparatus. Piezoelectric polymer-based vibration sensors will be placed along the feet, sides and top (tangent the wire suspension location) of the apparatus in an effort to monitor vibrational noise. A polycarbonate casing will be placed around the entire experiment to remove air current noise
2. **Procedure:** The silver plate will be positioned in its stationary zero-angle position (the same position as the plane of symmetry of our apparatus, to nullify its own gravitational effects on the experiment). The oscilloscope along with computer connected to it will be powered on, then the laser is powered on. Data collection software will start to run, producing a livestream feed of the data collected by the PSD as well as livestream feed of vibration sensor data collected. Once all devices have confirmed the experiment is properly in its starting position the cylindrical rods will be placed in their positions. The polycarbonate casing is placed over top the experiment, then data is collected over a large period of time (data collection time is dependent on position of cylinders, so it will vary). Once the data feed displays the experiment has reached a new equilibrium position the data collected from all devices is saved. The cylindrical rods are removed from the experiment

and the silver plate is allowed to return to its zero-angle position. The procedures are then repeated for a new position of the cylindrical rods.

3. Data Collection: We will be using a 1D PSD to record the displacement of the light with a 0.1% non-linearity. The PSD will be connected to a signal processing circuit that will convert the information gathered by the PSD into information readable by an oscilloscope which will then be connected to a computer set to run a LabView code that will record our data and display it in a graph with axis time and position through a livestream feed. The livestream feed allows us to identify errors in our experiment as they occur rather than waiting for the experiment to finish first. The data being displayed will be saved onto the computer as well for analysis and for use in publication of the experiment.
4. Data Analysis: Once we have our data in graph form we will compute the radius of equilibrium, damping coefficient and frequency of oscillations, then plug those values into our equation to give the Gravitational constant's value (due to report length constraints these equations have been omitted, they can be found in our proposal). This will be done for the largest possible measurable range of initial separation distance of the suspended mass and the cylindrical mass. For each position we will take several measurements and the average value along with the standard deviation will be computed to give the most accurate result. If a large enough variation in the value of the gravitational constant is observed, we will begin to attempt to match this variation to hypothesized gravitational constant variational equations; if none match our finding one will be developed that can explain the variation in its value.

Initial Results

Upon completion of our original design we had to make modifications due to the instability of the previous torsion bar. For that we had to identify possible solutions to this problem that could still yield the necessary data required to complete the experiment. We also have had to compute calculations for optimizing data collection in accordance to our PSD sensitivity area being a parameter constraint. We first had to identify the minimum possible change in angle of rotation that our PSD can measure, then the maximum possible change in angle. Using those two values as constraints in a Lagrange multiplier method for optimization, we were able to identify the best possible distance away from the torsion plate location to place the PSD that will allow for the largest range of mass separations. While optimizing the PSD location we also had the constraint that the PSD needs to be significantly far enough away to not effect the experiment. (calculations have been omitted due to report length restrictions, they will all be available in the final report and research publication).

Statement of Next Steps

Plan for Carrying Out Remainder of Project (including Timeline)

June

Complete assembling the experiment. [Brian C. Ferrari]

Design and assemble polycarbonate casing to reduce draft noise. [Brian C. Ferrari]

Obtain 1D-PSD and signal amplifier, last piece of equipment needed for experiment. [Brian C. Ferrari]

July

Familiarize ourselves with vibration sensor, PSD and amplifier. [Brian C. Ferrari, Salvador Rosa, Zachy, Cody Jordan, Ahad Bawany, Rachel Belton]

Collect sample data of noise with both devices. [Brian C. Ferrari, Zachy and Ahad Bawany]

Apply vibration damping techniques to minimize noise, then collect more data. Repeating until we have reached minimal noise in our experiment. [Brian C. Ferrari, Salvador Rosa, Zachy, Cody Jordan, Ahad Bawany, Rachel Belton]

August

Investigate a method for interpreting noise in the PSD through the vibration sensors. [Brian C. Ferrari, Zachy and Ahad Bawany]

Develop program or algorithm for removing/distinguishing noise vs actual data in our experiment. [Brian C. Ferrari, Zachy, Jamal Khayat]

September

Conduct experiment across various initial displacements. [Brian C. Ferrari, Salvador Rosa, Zachy, Cody Jordan, Ahad Bawany, Rachel Belton,]

Analyze data. [Brian C. Ferrari]

Begin preparations for publication of experiment. [Brian C. Ferrari]

October

Conduct experiment for orientation dependence hypothesis. [Brian C. Ferrari, Salvador Rosa, Zachy, Cody Jordan, Ahad Bawany, Rachel Belton]

Analyze data. [Brian C. Ferrari]

November

Submit abstract for APS march meeting under DGRAV. [Brian C. Ferrari]

Extra time reserved for unexpected problems

December

Complete paper for publication of experiment. [Brian C. Ferrari]

Submit paper to scientific journal. [Brian C. Ferrari]

Submit final report to SPS. [Brian C. Ferrari]

Bibliography

(1) Long, D. R. 1976 Nature, Lond. 260, 417

(2) C. M. Will, Theory and Experiment in Gravitational Physics (Rev.Ed., Cambridge University Press, Cambridge, 1993).

(3) Cook, A. H. & Chen, Y. T. I982 J. Phys. A 15, 1591

(4) JH Gundlach, SM Merkowitz - Physical Review Letters, 2000 – APS

(5) CK Lee - The Journal of the Acoustical Society of America, 1990

(6) G Rosi, F Sorrentino, L Cacciapuoti, M Prevedelli… - Nature, 2014

(7) Fujii, Y. 1972 Ann. Phys. 69, 494.

(8) Spero, R. E., Hoskins, J. K., Newman, R., Pelham, J. & Schultz, J. i98o Phys. Rev. Lett. 44, 1645.

(9) CC Haddock, N Oi, K Hirota, T Ino, M Kitaguchi… - Physical Review D, 2018 - APS