SOCIETY OF PHYSICS STUDENTS
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SPS Chapter Research Award Proposal

Project Proposal Title	Quantum Droplets: Pilot Wave Phenomena
Name of School	Loyola Marymount University
SPS Chapter Number	3913
Total Amount Requested	$432.91

Abstract

Bouncing droplets can self-propel laterally along the surface of a vibrated fluid bath by virtue of a resonant interaction with their own wave field. Interestingly, the walking droplets exhibit several features reminiscent of quantum particles (Bush, ARFM, 2015). In this project, we try to recreate some of the many striking pilot-wave phenomena.

Proposal Statement

Overview of Proposed Project

As a physics community, we expect to gain many different values from this project. Given that our department is a small one, with less than 30 students in total, there are not so many group projects taking place. Additionally, we have just recently started really pushing again our SPS chapter, trying to get as many students as possible interested in it. After attending PhysCon 2016, one advice we got from other chapters to achieve this was to carry research projects through SPS. Therefore, with this project we expect to unite our community and create an experience that will shape many students' career and make them feel part of something bigger that they belong to. Additionally, we believe this project will endure the pass of time, and will also impact future physics students that join our SPS chapter.

Background for Proposed Project

History:

In theoretical physics, the pilot wave theory was the first known example of a hidden variable theory, presented by Louis de Broglie in 1927 [1]. Its more modern version, the de Broglie–Bohm theory [2][3], remains a non-mainstream attempt to interpret quantum mechanics as a deterministic theory, avoiding troublesome notions such as wave–particle duality, instantaneous wave function collapse and the paradox of Schrödinger's cat.

The de Broglie–Bohm pilot wave theory is one of several interpretations of quantum mechanics. It uses the same mathematics as other interpretations of quantum mechanics; consequently, it is also supported by the current experimental evidence to the same extent as the other interpretations.

Principles:

The pilot wave theory is a hidden variable theory. Consequently:

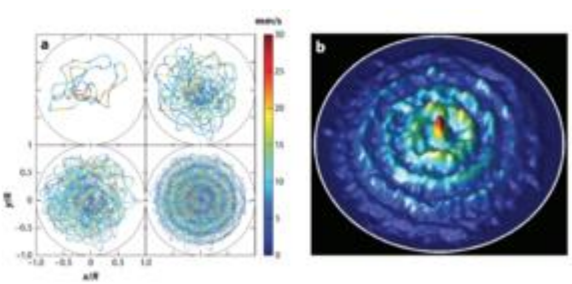
- the theory has realism (meaning that its concepts exist independently of the observer);
- the theory has determinism.

The positions and momenta of the particles are considered to be the hidden variables. However, the observer not only doesn't know the precise value of these variables, but more importantly, cannot know them precisely because any measurement disturbs them.

A collection of particles has an associated matter wave, which evolves according to the Schrödinger equation. Each particle follows a deterministic trajectory, which is guided by the wave function; collectively, the density of the particles conforms to the magnitude of the wave function. The wave function is not influenced by the particle and can exist also as an empty wave function.[4]

The theory brings to light nonlocality that is implicit in the non-relativistic formulation of quantum mechanics and uses it to satisfy Bell's theorem. Interestingly, these nonlocal effects are compatible with the no-communication theorem, which prevents use of them for faster-than-light communication, and so is empirically compatible with relativity.

Consequently, the pilot wave theory shows that it is possible to have a realistic and deterministic hidden variable theory, which reproduces the experimental results of ordinary quantum mechanics. The result however is nonlocality.



This figure describes (a) A walker in a circular corral. Trajectories of increasing length are color-coded according to the droplet's local speed (b) The probability distribution of the walker's position corresponds roughly to the amplitude of the corral's Faraday wave mode. [5]

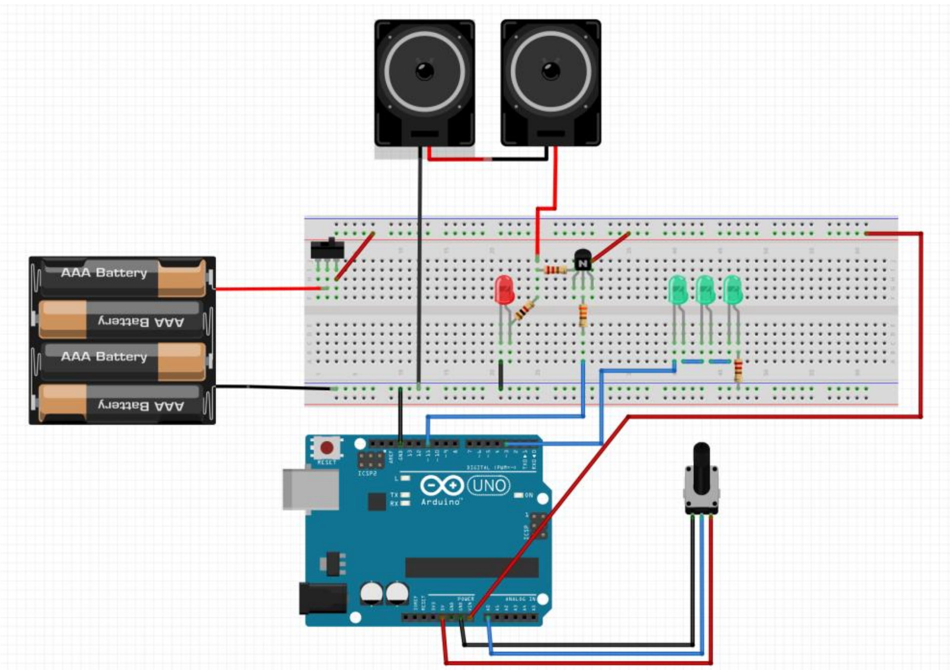
Expected Results

We expect to calculate the path probabilities described by the walking droplet in different scenarios and compare these results to those of different quantum mechanics interpretations, specifically focusing on Broglie–Bohm pilot wave theory.

Description of Proposed Research - Methods, Design, and Procedures

The experiment will consist of a cylindrical beaker (15cm Petri Dish) mounted on a vibration exciter (Surface Transducer / Loudspeaker) powered with a sinusoidal signal from an Arduino UNO Board. Everything is mounted on special acoustic absorbers to eliminate the influence of external vibrations. The beaker has an interior diameter of 150 mm and is 15 mm depth. The fluid used in this series of measurements will be a high purity Silicone Oil which has a kinematic viscosity of 20 cst. The container will be filled with this oil to a depth of 10mm. The beaker would bitrate at a frequency of around 260 Hz (just below the intensity required for the formation of Faraday's Waves on the surface). The fact that this frequency lies in the audible range means that we can make use of a normal sub-woofer speaker instead of a more expensive mechanical oscillator to produce the oscillations.

We will record the results of the experiments conducted inside this cylindrical beaker using Raspberry Pi Camera Module which has Slow-Motion capabilities (90 Hz sample rate). The process will be automatized via a Bash script running on the Raspberry Pi 3. In order to maximize the visibility of the phenomena (the small waves in the surface and the jumping droplets) we will point an LED Panel directly to the surface of the Silicone Oil which we expect will produce some unique patterns.



The diagram above describes the set-up. A Potentiometer resistor will provide input to the Arduino board and will function as our interface to tweak the frequency for the experiment. The current value will be shown to the user through a Seven Segment display (represented here as 3 green LED's). The Arduino will output the signal to the speaker using Pulse Width Modulation, which will be amplified by an NPN transistor connected to a 9v source.

We have already built a prototype using a IOIO board and a small speaker powered by an Android Phone that shows promising results. A description of this prototype project and the code can be found at our GitHub repository.

Plan for Carrying Out Proposed Project

- Personnel
    - Initially his project is an initiative of 3 SPS members at LMU: Luciano Manfredi (Junior, Physics and Pure Math major), Juan Neri (Sophomore, Physics and Computer Science major) and Matthew Guhl (Freshman, Physics major). We expect for more SPS members of the LMU chapter to begin collaboration in the project during the year, especially as we receive incoming students in Fall 2017

    - We will receive help form Anatol Hoemke, Laboratory Manager at LMU who has experience with experiments involving fluid dynamics.
- Expertise
    - Altogether the members of the team have taken the following relevant coursework that provide necessary background for the experiment:
        - ELEC 210 Electric Circuit Analysis
        - ELEC 213 Electric Circuit Analysis Lab
        - PHYS 195 Waves and Light
        - PHYS 301 Electromagnetic Fields
        - PHYS 321 Quantum Mechanics I
        - PHYS 322 Quantum Mechanics II
        - PHYS 451 Thermodynamics and Statistical Mechanics
        - PHYS 461 Elementary Particle Physics
        - MATH 355 Methods of Applied Mathematics
        - MATH 360 Introduction to Probability and Statistics
        - CMSI 185 Computer Programming
        - CMSI 387 Operating Systems
- Upon contacting Anatol Hoemke, Laboratory Manager at LMU, he provided us with a room which has enough space to carry out this experiment. The room is also equipped with monitors which we plan to use to visualize the Raspberry Pi Camera Module footage. The department also has an oscilloscope which can be used to debug the code Arduino running in the Arduino (scrutinize inputs and outputs)

Project Timeline

We plan on building the experimental set-up during the Spring semester of 2017. We plan on starting on January 16, the second week of classes in the Spring semester, after the first SPS chapter meeting had taken place on January 13. The deadline would therefore be May 5 (first week of May) to finish the construction of the hardware and for having a working software that will control the frequency with the Arduino and record the experiment with the Raspberry Pi 3. By May 31 we should have some preliminary results with Bouncing droplets on the surface of our liquid for our interim report.

The Fall semester of 2018 will be entirely focused on running experiments that replicate quantum phenomena according to the pilot-wave theory such as Circular orbits in a harmonic potential, Non-specular reflection of walking droplets, Double Slit interference, particle in a box and more. By December 10 we plan on having enough data from this experiments to compare it with the theoretical descriptions of the pilot-wave interpretation. A final report will be submitted by December 31.

Budget Justification

The Key components for this experiment, as detailed in the Description section are:

- Requested Materials
    - For the Circuit
        - Arduino
        - Raspberry Pi 3
        - Surface Transducer
        - Loudspeaker
    - For the Experiments

        - 15cm Petri Dish
        - Silicone Oil 20 cst High Purity
        - Drop Generator
        - RGB LED Panel
        - Raspberry Pi Camera Module
        - Drop Generator
- Materials provided by Loyola Marymount University
    - High Definition computer monitors
    - Oscilloscope

The Arduino and Raspberry will be the main elements that control the experiment. The Surface Transducer and the Loudspeaker will be used to provide the oscillatory force to the surface (each will be used for different ends in specific experiments). The drop generator is a key component in this experiment, for it will ensure that all drops have the same properties, ensuring repeatable results. Finally, the LED panel and camera module will be used to collect clear data from results, analyze the information and share it with the community. We will also use some of the most relevant pieces of information to submit our chapter research award final report on December 31.

Bibliography

[1] de Broglie, L. (1927). "La mécanique ondulatoire et la structure atomique de la matière et du rayonnement". Journal de Physique et le Radium. 8 (5): 225–241. Bibcode:1927JPhRa...8..225D. doi:10.1051/jphysrad:0192700805022500.
[2] Bohm, D. (1952). "A suggested Interpretation of the Quantum Theory in Terms of Hidden Variables, I". Physical Review. 85 (2): 166–179. Bibcode:1952PhRv...85..166B. doi:10.1103/PhysRev.85.166.
[3] Bohm, D. (1952). "A suggested Interpretation of the Quantum Theory in Terms of Hidden Variables, II". Physical Review. 85 (2): 180–193. Bibcode:1952PhRv...85..180B. doi:10.1103/PhysRev.85.180.
[4] "Six possible worlds of quantum mechanics". Foundations of Physics. 22 (10): 1201–1215. Bibcode:1992FoPh...22.1201B. doi:10.1007/BF01889711.
[5] Harris, Daniel M.; Bush, John W. M. (2013). "The pilot-wave dynamics of walking droplets" (PDF). Physics of Fluids. 25: 091112. doi:10.1063/1.4820128. Retrieved 27 November 2016.