**Imaging and Analysis of Hydrodynamic Quantum Analogs**

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**Abstract**

Hydrodynamic quantum analogs consist of a small droplet of viscous fluid that is self-propelled across an oscillating bath of the same fluid. Continuous vertical bouncing, and walking horizontal motion, of the droplet can be achieved with careful control over the frequency and amplitude of oscillation. With each rebound, the droplet receives transverse kicks in its motion dependent on the waves of its previous bounces. With variations in bath geometries and subsurface structures, the probability distribution of the droplet’s trajectory can be manipulated to induce fascinating behavior. Over short timescales, a droplet will exhibit seemingly random trajectories. However, when the droplet is observed over long timescales, patterns in the cumulative motion of the droplet begin to emerge. The patterns this system maps out over long timescales demonstrate a compelling macroscopic analogy to Louis de Broglie’s double-solution theory of quantum mechanics. We present the results from various pilot-wave hydrodynamic analog experiments, analysis of which has provided valuable insight into the analogy between a bouncing macroscopic oil droplet and the quantum behavior of microscopic particles.

**Novel Imaging System**

The optical arrangement shown allows for the simultaneous observation of the hydrodynamic pilot-wave and the droplet position. This scheme enables the visualization of the short-term chaotic motion of the droplet, the droplet’s pilot-wave, as well as the long-term statistical build up of the droplet’s trajectory heat-map, helping make direct connections between the pilot-wave and droplet motion across a range of timescales.

**Faraday Threshold and the Quantum Corral Analog**

The droplet trajectory heat map time-series below exhibit the droplet’s motion as the oscillator’s amplitude of oscillation is varied from an amplitude in excess of the onset of Faraday standing waves to that just below the onset of Faraday standing waves, i.e., the amplitude at which “walking” droplet and interference effects occur, and back again. The long-term probabilistic trajectory of the droplet is directly dependent on the forcing conditions of the bath. The forcing conditions of the bath provide the energy necessary to sustain the bouncing droplet and resulting wave field. Additionally, forcing the bath at the Faraday frequency preconditions the oscillating medium (oil) for a monochromatic wave field.

**Further Study**

A quantum mirage is the result of any arrangement of atoms or other defects that produce a buildup of surface-state electron amplitudes at two locations within a coherence length of an electron. In a particular quantum mirage experiment, a single Cobalt (Co) atom produced a spectroscopic mirage in an elliptical coral constructed of magnetic Co atoms on a Cu(111) substrate. The mirage was produced more than 70 Å away. Considering a Cobalt atom is approximately 192 pm, or 1.92 Å, in radius (Van der Waals radius), the projection of the atom’s properties across a distance approximately 18 times its diameter to an otherwise empty focus of an elliptical coral geometry is bizarre, to say the least.

In an effort to further probe the analogy between pilot-wave hydrodynamics and quantum mechanics, an elliptical oil bath arrangement was designed containing a shallow region of oil surrounding the portion of the elliptical bath geometry designated to contain the droplet. This shallow region will simulate the leaky walls of a quantum corral and prevent the oil droplet from interacting with the hard barrier surface of the oil bath as it walks across the oscillating oil surface. Furthermore, the depth of the oil in the oil bath will be conducive to standing Faraday waves—based on previous circular coral research.

**Quantum Entanglement**

Equally fascinating to the quantum mirage, is the theory of quantum entanglement in which entangled quantum systems interact across large distances, famously referred to by Albert Einstein in a personal letter to Max Born as “spooky action at a distance.”

An oil bath geometry constructed of two merged circular coral geometries (right) has been developed. This oil bath geometry will be explored with the intent to produce droplet behavior reminiscent of quantum entanglement.