Quantum Mechanical and Optical Inspirations in Surface Gravity Water Waves: An Analogy Exploration

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Analogies between quantum and classical systems can be found in many areas of physics, from optics and acoustics to condensed matter and particle physics. Surface gravity water waves, for example, have been shown to exhibit analogies to both quantum mechanics and optics. By exploring such analogies, we can gain new insights into the fundamental behavior of both quantum and classical systems. While the two regimes of physics operate on vastly different scales, they are related through the notion of wave-particle duality. This duality allows quantum objects, such as photons and electrons, to display both wave-like and particle-like properties, like classical systems.

In that regard, the phase of a matter wave, governed by the Schrödinger equation, plays a crucial role in solving fundamental problems in quantum mechanics. However, it is quite difficult to measure the full wave packet (both amplitude and phase) of matter waves. In this research, we propose both theoretical and experimental study of quantum mechanical analogies with hydrodynamics, by measuring the propagation dynamics of surface gravity water waves, which, under certain circumstances, obey the Schrödinger equation. We began this research by exploring the propagation dynamics of Gaussian and Airy wave packets and successfully observed the Kennard cubic phase for the first time. We further investigated the propagation dynamics of solitons in linear potential, a problem in which the wave packets maintain their temporal shape but accelerate. Then, we explored various systems such as the Talbot effect (or Talbot carpets) and successfully showed experimentally that the Talbot effect occurs not only in the amplitude but also in the phase. In addition, we explored the Talbot effect in the nonlinear regime and observed for the first time the absence of fractional Talbot-effect, due to interference of the periodic wavepackets in a nonlinear medium. Currently, we study deeper analogies between quantum mechanics and surface waves and aim to measure scattering of wave packets from an inverted oscillator potential, quantum decoherence, ballistic wave packets as well as other different time-dependent potentials and an analogy of a black holes in phase space. Furthermore, we have recently discovered that our experimental setup allows measuring and studying Bohm trajectories and quantum potentials of different wave packet types, including two/three slits and Airy slits. In addition, this approach can also lead to an experimental observation of the Wigner distribution of the wave function or the adjunct entropy. Moreover, we have recently shown that our system can emulate antireflection temporal coatings, dark focusing and diffractive focusing and guiding of waves. These experiments aim to serve as a new type of a platform for different aspects of complex optical systems fundamentals as well as fundamental quantum phenomena.