Surface gravity waves: Quantum phenomena in classical waves

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The time evolution of a wave function in quantum mechanics is analogous to that of surface gravity water wave pulses. In our studies, we have recently utilized this analogy and have measured the cubic phase of accelerating wave packets in a linear potential for cases of linear and nonlinear propagation, including a case of initial non-zero momenta [1,2].

Inspired by these successful experiments, we extend this analogy to a study of electromagnetic fields around black holes and different types of amplitude and phase singularities, including a logarithmic phase singularity. The analogous system in hydrodynamics is obtained by generating Gaussian wave packets that propagate in a time-dependent potential that has a shape of an inverted harmonic oscillator. Depending on the wave packet energy with respect to the peak energy of the potential, we observe three different cases: i) wave reflection, in the case of low energy waves. ii) wave stopping when the wave energy matches the potential peak energy or iii) wave transmission, for higher energy waves. We also studied this problem using Weber wave packets, which are the eigenstates of the inverted harmonic oscillator system. An interesting observation is that even without a potential, an initial state which is an energy eigenstate of the inverted harmonic oscillator would evolve in free space until it reaches an amplitude singularity, accompanied by a logarithmic phase singularity.

Furthermore, we propose methods to study the propagation of wave packets in an open system, coupled with the vacuum state. In the latter, we have managed to observe phenomena which is analogous to that quantum decoherence.

[1] G. G. Rozenman et al. Amplitude and Phase of Wavepackets in Linear Potential, Phys. Rev. Lett. 122, 124302 (2019).

[2] G. G. Rozenman et al. Quantum Mechanical and Optical Analogies in Surface Gravity Water Waves, Fluids 4(2), 96 (2019).