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Classical and Quantum Dynamics for a Parametric Oscillator with Analytical Solutions and Comparison with the Damped Harmonic Oscillator

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For quadratic Hamiltonians, the time-dependent Schrödinger equation possesses Gaussian wave packets as exact solutions. They are completely determined by two parameters, the maximum and the width, where both can be time-dependent. The time-dependence of the maximum is determined by the classical Newtonian equation of motion; the width obeys a complex quadratically nonlinear Riccati equation or an equivalent real nonlinear Ermakov equation. All quantum dynamical properties can easily be constructed from the solutions of these equations. In addition, the link to the corresponding classical dynamics is supplied via linearization of the Riccati equation to a complex Newtonian equation. Real and imaginary parts of this equation are not independent of each other but connected via a kind of conservation law in the complex plane. Knowing the solution of one part makes it possible to determine the solution of the other and, thus, the solution of the Ermakov equation. Consequently, explicit expressions can be obtained immediately for all quantum dynamical properties.

Comparing the wave packets with the solutions of the diffusion equation –also Gaussian with time-dependent width –leads to a parametric oscillator with frequency inversely proportional to time. Detailed analysis enables the elimination of certain divergencies and shows similarities with the damped harmonic oscillator for the aperiodic limit. For different choices of a free parameter, similarities with undercritical and overcritical damping can also be shown.

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