



Scattering of a wave packet by the Pöschl-Teller potential well

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Abstract

We investigate the scattering of a wave packet by the Pöschl-Teller potential in momentum representation. The scattering dynamics of the wave packet for a long-time evolution is feasible in this representation. With the wave function in momentum space, we can construct the time-dependent phase space Wigner function. The corresponding density function in coordinate space is then calculated through the Wigner function. The reflectionless wave packet for integer ν and partially reflected for non-integer ν are demonstrated by analyzing the Wigner function.

1. Introduction

A wave packet scattered by a potential will contain a transmitted part and a reflected part generally. But the Pöschl-Teller potential $V(x)$, under some specific condition, shows unusual reflectionless property. The time-dependent Schrödinger equation (TDSE) for the problem is

$$i\hbar \frac{d\Phi}{dt} = -\frac{\hbar^2}{2m} \frac{d^2\Phi}{dx^2} + V(x)\Phi, \quad (1)$$

$$V(x) = -\frac{\hbar^2}{2m} \frac{\nu(\nu+1)}{\cosh^2(x/\alpha)}. \quad (2)$$

As Flügge [1] showed, for solutions in the following asymptotic form

$$\begin{aligned} \Phi(x) &= e^{ikx} + Re^{-ikx}, \text{ for } x \ll 0, \\ \Phi(x) &= Te^{ikx}, \text{ for } x \gg 0, \end{aligned} \quad (3)$$

the reflection and transmission coefficient will be

$$|R|^2 = \frac{1}{1 + \eta^2}, \quad |T|^2 = \frac{\eta^2}{1 + \eta^2}, \quad (4)$$

$$\eta = \frac{\sinh(\pi k\alpha)}{\sin(\pi\nu)}. \quad (5)$$

When $\nu = \text{integer}$, $\eta \rightarrow \infty$, $|R|^2 \rightarrow 0$ and $|T|^2 \rightarrow 1$, all the incident plane waves at arbitrary energy $\hbar^2 k^2 / 2m$ will be reflectionless. Kirianscheva and Kuzmin [2] compared numerically the scattering of a Gaussian wave packet by the Pöschl-Teller potential of $\nu = 1$ and by the square-well potential. Numerically they found the wave packet passes through the well faster than a free-space Gaussian wave packet, and the width becomes narrower after scattering. Lekner [3, 4] constructed analytically the reflectionless incident wave packets from eigenfunctions of $\nu = 0, 1, 2$. He derived the formulas for group velocity, and width together with numerical simulations and confirmed the speed up and narrower width compared to the free-space Gaussian wave packet showed in [2]. He showed that the number of elementary functions in eigenstates increases quickly from $\nu = 1$ to $\nu = 2$ and commented that as integer ν increases, the eigenstates become more and more complicated. The eigenstates for non-integer ν in terms of elementary functions are hard. Lekner gave examples of electromagnetic wave reflection by dielectric functions [5]. The special property of reflection at $\nu = \text{integer}$ was attributed to the critical binding and symmetry of $V(x) = V(-x)$ [3]. Tong [6] studied the analytic properties of scattering states of the Pöschl-Teller potential in complex energy plane. At an integer value of ν , the spreading of a Gaussian wave packet

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