Is the speed of light in tunneling faster than the speed of light in a vacuum???

(In these cases, physicists still do not understand the nature of time tunneling in the potential well.) In classical physics, if we want to know how long it takes for a particle to travel, we need to know both the start and end times. But in quantum models, such as the "quantum clock" model, the only thing that can be observed and measured is the time difference (or the travel time), not the absolute start time. (There is no universal reference for determining when tunneling should begin.) When the clock shows that the particle has only been inside the barrier for "say, 1 femtosecond," but because we don't know when this 1 femtosecond started, we can't tell the information from one point to another. This is one of the main reasons why quantum tunneling remains consistent with special relativity, even though the "effective passage speed" apparently exceeds the speed of light. In quantum mechanics, we can never say with certainty "when" a particle entered a particular region (e.g., a potential well). Not yesterday, not today, and not in the future. (I can only enter the well, see it, and calculate its time difference.) The articles have explained the matter very vaguely. In a word, the phase velocity can exceed the speed of light, but this does not mean that information can also travel at the speed of light. Of course, today's experiments say so. I believe that information will also be proven in the future to travel at a speed exceeding the speed of light. Of course, we know that the phase velocity can travel faster than light. In quantum, if we make the well any larger or smaller, we will observe the same amount of tunneling time. This does not fit with classical theory because if the path is larger, the time must be longer to travel the path. But in quantum mechanics, this is not the case and the time will be the same. I believe that if we make the space smaller, the dispersion of space will decrease by taking into account the uncertainty principle, and we will see the dispersion of momentum, and that as a result of this event, we will observe that the phase oscillation will increase, and as a result of the increase in oscillation, we will have a higher phase velocity, and the phase velocity can exceed the speed of light to some extent. And this is that we have the same time at once in the conditions where we either make the space larger or smaller. There are various ways to get the time it takes for a particle to pass through a well, but what caught my attention was the residence time formula, which does not give the time it takes for the particle to pass through, but rather the time it is present. I tried to come up with a new formula, but I had trouble with the dimensions and I couldn't come up with a formula that had the time dimension and the necessary standards, but my formula was very similar, or my way of thinking was similar, to the residence time formula. article amsmath physics

Calculation of Dwell Time for a Rectangular Potential Barrier

Definition of Dwell Time

Dwell time is defined as the average time a quantum particle spends inside a region (here, the potential barrier), regardless of whether it eventually transmits or reflects:

$$\tau_D = \frac{\int_{x_1}^{x_2} |\psi(x)|^2 \, dx}{j_{\text{in}}}$$

Rectangular Potential Barrier

Let the potential be:

$$V(x) = \begin{cases} 0 & x < 0 \\ V_0 & 0 \le x \le a \\ 0 & x > a \end{cases}$$

Assume $E < V_0$, so the particle undergoes tunneling. In the region $0 < x < a$, the wavefunction inside the barrier is:

$$\psi(x) = Ce^{-\kappa x} + De^{\kappa x}, \quad \text{where } \kappa = \sqrt{\frac{2m(V_0 - E)}{\hbar^2}}$$

In the typical tunneling case, we consider only the decaying exponential:

$$|\psi(x)|^2 = |C|^2 e^{-2\kappa x}$$

$$\int_0^a |\psi(x)|^2 \, dx = |C|^2 \int_0^a e^{-2\kappa x} dx = |C|^2 \cdot \frac{1 - e^{-2\kappa a}}{2\kappa}$$

In the region $x < 0$, if the incident wave is $\psi(x) = Ce^{ikx}$, then the incoming probability current is:

$$j_{\text{in}} = \frac{\hbar k}{m} |A|^2, \quad \text{where } k = \sqrt{\frac{2mE}{\hbar^2}}$$

Putting everything together:

$$\tau_D = \frac{|C|^2 \cdot \frac{1-e^{-2\kappa a}}{2\kappa}}{\frac{\hbar k}{m}|A|^2} = \left(\frac{m}{\hbar k}\right) \cdot \left(\frac{|C|^2}{|A|^2}\right) \cdot \left(\frac{1 - e^{-2\kappa a}}{2\kappa}\right)$$

The ratio $\frac{|A|^2}{|C|^2}$ can be determined from the continuity conditions at the boundaries of the potential.