Bounds and enhancements for the Hartman effect

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The Hartman effect occurs when the time of passage t_d of the transmitted wave packet in a tunneling collision of a quantum particle with an opaque square barrier becomes essentially independent of the barrier width d (t_d could be defined as the time of passage of the peak, or by means of some average of arrival or detection times). Since the velocity, when defined by comparing the instants of the incoming and outgoing peaks, may exceed arbitrarily large numbers, and there is a related effect for photons or electromagnetic waves, this "fast tunneling" has been frequently interpreted as, or related to, a "superluminal effect", even though, of course, the velocity of light c plays no role in the non relativistic Schrödinger equation.

A related and controversial discussion is that of defining a "tunneling time". Some of the definitions proposed lead in tunneling conditions to very short times, which can even become negative in some cases. This may seem to contradict simple concepts of causality. The classical causality principle states that the particle cannot exit a region before entering it. Thus the traversal time must be positive. When trying to extend this principle to the quantum case, one encounters the difficulty that the traversal time concept does not have a straightforward and unique translation in quantum theory. In fact for some of the definitions proposed, in particular for the so called "extrapolated phase time", the naive extension of the classical causality principle does not apply for an arbitrary potential, even though it does work in the absence of bound states. Indeed, when bound states are present, e.g., for square wells, the advancements may be much more important (even though also bounded by a causal principle) at low energies than those characteristic of the Hartman effect for square barriers. Thus, it seems appropriate to rename the time advancement due to the bound states as an "ultra Hartman effect". This enhanced effect may be readily observable since the low energy time advancement is accompanied by high transmission probabilities close to the onset of a new bound state.

Reference:

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