Superluminal Speed, the Tunnel Effect, and Quantum Mechanics

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April 16, 2024

Abstract

We investigate consequences of Galilean relativity principle postulating superluminal observers' existence, suggesting that field theory emerges from the extended special relativity.

1 Introduction

Although quantum mechanics is a very successful theory, there are many conflicting views over its interpretation [1, 2]. One of the most difficult interpretational problems is the nature of measurement. There is also a task of reconciliation of quantum theory with Einstein gravity, aiming at a theory of quantum gravity [3].

Recently, a promising approach, deriving quantum behaviour from special relativity and based on superluminal observers, has been proposed [4–6]. There is, thus, a problem with the reality of superluminal velocities. A possible place where superluminal velocities may be detected is the tunneling effect [7–9].

2 Superluminal observers and quantum theory

The standard subluminal Lorentz transformation in $1+1$ dimensions:

$$\left.\begin{aligned} x' &= \frac{x - Vt}{\sqrt{1-\frac{V^2}{c^2}}} \\ t' &= \frac{t - Vx/c^2}{\sqrt{1-\frac{V^2}{c^2}}} \end{aligned}\right\}, \quad V < c, \tag{1}$$

can be extended for superluminal velocities [4, 10]:

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$$
\left.\begin{array}{l}
x' = -\dfrac{V}{|V|}\dfrac{x - Vt}{\sqrt{\frac{V^2}{c^2} - 1}} \\
t' = -\dfrac{V}{|V|}\dfrac{t - Vx/c^2}{\sqrt{\frac{V^2}{c^2} - 1}}
\end{array}\right\}, \quad V > c. \tag{2}
$$

It has been demonstrated that such an extension of special relativity does not lead to causal paradoxes [4, 5]. Most interestingly, it has been shown that subluminal *and* superluminal Lorentz transformations (1) *and* (2) lead to non-deterministic dynamics.

Moreover, the superluminal transformation (2) can be generalized for $1 + 3$ dimensions, and this extension gives rise to field theory [6].

3 The tunnel effect

Consider an alpha decay, for example:

$$
{}^{241}_{95}Am \longrightarrow {}^{237}_{93}Np + {}^{4}_{2}He + \gamma. \tag{3}
$$

Alpha decay is fundamentally a quantum process since the alpha particle, classically forbidden to escape, has to tunnel through a barrier. Some computations and experiments suggest that particles tunnel with superluminal velocity [7–9].

Consider, for example, the time-dependent Dirac equation in 1+3 dimensions in a potential $V(z)$ depending on the z variable only. After the separation of variables, we get:

$$
i\hbar\frac{\partial}{\partial t}\begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix} = \left(ic\hbar\sigma^1\frac{\partial}{\partial z} + mc^2\sigma^3 + V(z)\right)\begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix}, \tag{4}
$$

where $\sigma^1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$, $\sigma^3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ are the Pauli matrices and $V(z)$ is a square barrier potential [8]. It turns out that the tunneling is superluminal, however, with very low transmission probability [8].

4 Conclusions

In Ref. [6] the authors argue that the postulate of Galilean relativity principle, taking into account subluminal *and* superluminal observers, shows that field theory follows from the extended special relativity.

In accordance with the idea that all inertial observers, subluminall as well as superluminal, should be treated equally, we show that solutions with normal and tachyonic dispersion relations show up for the Klein-Gordon equation (in appropriate units):

$$
\frac{\partial^2\Psi}{\partial t^2} - \left(\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\Psi}{\partial z^2}\right) + m^2\Psi = 0. \tag{5}
$$

Indeed, while the following standard form:

$$u_k\left(t, \overrightarrow{r}\right) = n_k e^{-i\left(\omega_k t - \overrightarrow{k}\cdot\overrightarrow{r}\right)}, \tag{6}$$

solves (5), provided that $\omega_k^2 = \left|\overrightarrow{k}\right|^2 + m^2$, where n_k is a normalization factor, there is also another class of solutions:

$$\tilde{u}_k\left(t, \overrightarrow{r}\right) = \tilde{n}_k e^{\pm\left(\omega_k t - \overrightarrow{k}\cdot\overrightarrow{r}\right)}, \tag{7}$$

with tachyonic dispersion relation $\omega_k^2 = \left|\overrightarrow{k}\right|^2 - m^2$.

Note that for $\omega_k t - \overrightarrow{k}\cdot\overrightarrow{r} > 0$, the form $\tilde{u}_k\left(t, \overrightarrow{r}\right) = \tilde{n}_k e^{-\left(\omega_k t - \overrightarrow{k}\cdot\overrightarrow{r}\right)}$ is a decaying, tunnel-type solution for growing t.

Therefore, we think that superluminal velocities may arise in the tunnel effect; see also Section 3.

We thus consider the alpha decay; see, for example, Eq. (3). Suppose that we observe an alpha particle ${}_2^4He$ ejected from the nucleus and suppose that it was superluminal under the barrier. Hence we cannot ascribe a cause (inside the nucleus and prior to decay) to the observation. To sum up, we have to view the decay as non-deterministic.

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