Debunking the Anti-Tachyon Myths

Charles Schwartz, University of California, Berkeley, CA.
schwartz@physics.berkeley.edu, December 13, 2020
posted at `http://www.ocf.berkeley.edu/~schwrtz/debunk2.pdf`

Some people believe that the Earth is flat; and they can see this is true with their own eyes. Physicists are convinced otherwise; and they can cite abundant evidence on their side.

However, when it comes to Tachyons (faster-than-light particles), a great many physicists believe that they do not, and some will say that they can not, exist; and a number of reasons are recited in support that that prejudice.

In my several papers exploring mathematical frameworks for how Tachyons might fit into physical theory and experiments I have taken the trouble to lay out careful reasoning to debunk those prejudices. Do I have to review all those arguments in every new paper I write? This note is posted to serve that purpose.

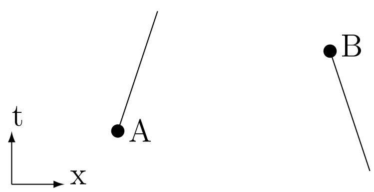
Firstly, all my work is done strictly within the established mathematical frameworks of Special and General Relativity. (Some other authors have violated those bounds.)

The argument most commonly heard against the existence of tachyons (anything that travels faster than light) is this: If tachyons existed, one could, in principle, send a signal into the past and this would lead to an unbearable logical paradox. (This so-called paradox is sometimes named the "antitelephone.")

This claim has been debunked some time ago [1]; and here I shall give my own critique.

The phrase "send a signal into the past" is utter nonsense. Said more professionally, this phrase is an oxymoron, meaning that it is self-contradictory in terms of the language used.

Let me show this by means of some diagrams that are basic tools in connecting the mathematical principles of the Special Theory of Relativity to the way we physicists talk. The picture below is a space-time diagram that shows two events, labeled A and B, each with a worldline showing the trajectory of a particle (or a signal) ending at that event. The picture at A is described by the word "send" and this means that the particle moves farther and farther away from the location of event A, as time moves forward. The picture at B is described by the word "receive" and this means that the particle moves closer and closer to the location of event B, as time moves forward. Thus the words "send" and "receive" each have within their definition (at least as sensible physicists speak) a specific sense of time evolution. The phrase "send a signal into the past" explicitly violates this definition of the word "send."



Please note that I have not yet said anything about tachyons. This comes next.

If the particle being sent or received is an ordinary particle (or a photon), then the trajectory will lie within (or on) the lightcone centered at the endpoint A or B. This property will remain the same when either process is viewed from a different Lorentz frame. Thus, for ordinary particles or light we can say that the assignment of the word "send" or "receive" is invariant under (orthochronous) Lorentz transformations. For tachyons, however, the particle trajectory lies outside the lightcone; and this means that a Lorentz transformation can change the appearance of the process. The experiment at A (sending the particle) may be seen by observers in a different Lorentz frame as a version of experiment B (receiving the particle).

Thus, one way to debunk the "antitelephone" paradox is to say that you have misused Special Relativity by tieing together two observations that are actually made in different Lorentz frames and claiming this is physical reality. It is not. The error is to assume that the word "send" always has a Lorentz invariant meaning, when, in fact, that is true only for a select set of particles, excluding tachyons.

It may seem strange that, as one considers viewing the experiment at A from a sequence of Lorentz frames that move faster and faster away from the original frame, an experiment that was once termed "send" becomes instantaneously transformed into "receive". Next, I note a way to remove this annoyance.

In my 2011 JMP paper, Appendix A looks at a scenario of sending tachyon signals between earth and a distant rocket ship, alleging *a causal paradox*. It is argued that an exchange of tachyon signals can lead to a response arriving before the original message was sent out. Simply replacing the point particle by a wave packet shows that, when one carries out the relevant Lorentz transformation, the distinction between sending (emitting) and receiving (absorbing) a tachyon can disappear in a continuous manner.

In my 2016 IJMPA paper, I state the appropriate *principle of causality* for tachyons - no propagation slower than the speed of light; and this leads to a consistent mathematical formalism for quantizing such fields. This provides an alternative to the canonical formalism, which is wrong for tachyon fields.

In my 2018 IJMPA paper, Section 2 examines the role of tachyons engaged in a general multi-particle interaction. The common idea that *negative energy states* imply physical instability of the system is debunked by recognizing that the naming of *in* and *out* states is not Lorentz invariant. The total energy and momentum are still conserved.

In my 2016 paper on quantizing tachyon fields, especially for the spin 1/2 (Dirac) case, I deal with the *Little Group O(2,1)* by introducing an indefinite metric (the helicity) into the Fock space.

Then there are experiments, a number of which over the years have claimed to observe neutrinos as tachyons, and then been revised to the opposite conclusion. The 2011 *OPERA experiment* looked at 20 GeV neutrinos and first reported that they travelled faster than light by 1 part in 40,000. That would imply a tachyon mass of about 100 MeV. But we know that neutrino mass is around 0.1 eV; and the excess velocity (v-c) goes as the square of the mass-to-energy ratio. That puts us 14 orders of magnitude below the original (wrong) observation.

Finally, there are theoretical efforts to derive the existence of known particles from some abstract field with complicated self-interactions. The simplest model is a scalar field with a potential that looks like W. If one expands around the central peak, then the resulting particles are found to be tachyons (negative mass-squared). But then one recognizes that those states are unstable; one should instead expand about the minima of W, where one gets ordinary particles. I am not involved in that sort of theorizing.

I start with the question: If tachyons do exist, how would we describe them within our customary mathematical frameworks? The starting point is the relativistically invariant form for any 4-vector (e.g., the energy-momentum of a particle):
$p^\mu p_\mu = constant$. That constant may be positive, zero, or negative.

A recent criticism of tachyon-neutrinos is this. Take the Lagrangian density for an ordinary Dirac field,

$$\bar{\psi}[i\gamma^\mu \partial_\mu - m]\psi, \quad \bar{\psi} = \psi^\dagger \gamma^0 \tag{0.1}$$

and replace m by im. The result is non-Hermitian, so the theory derived from this will violate unitarity - conservation of total probability. But that is not how I do it. I insert im in the Dirac differential equation, derive the equation for the adjoint field $\psi^\dagger$ from this, and then construct a Lagrangian density that will produce both of those equations of motion. The result is,

$$\bar{\psi}\gamma_5[i\gamma^\mu \partial_\mu - im]\psi. \tag{0.2}$$

With the γ_5 inserted this is all Hermitian. So there is no problem here.

I have also noted earlier that the conserved current and energy-momentum tensors are,

$$j^\mu = \bar{\psi}\gamma_5\gamma^\mu\psi, \tag{0.3}$$
$$T^{\mu\nu} = (im/4)\bar{\psi}\gamma_5[\gamma^\mu \overleftrightarrow{\partial^\nu} + \gamma^\nu \overleftrightarrow{\partial^\mu}]\psi. \tag{0.4}$$

While all these expressions are Hermitian and transform appropriately under proper orthochronous Lorentz transformations, they have the opposite behavior under parity (space inversion) compared to ordinary Dirac theory. Is this a problem? Neutrinos are supposed to interact with other particles in a way that maximizes parity violation; so maybe this is a good sign!

Furthermore, given such forms, we would not want to couple this tachyon-Dirac field to the electromagnetic field. That is good news for our theory for two physical reasons: a charged tachyon would rapidly dissipate its energy via Cherenkov radiation; and neutrinos are uncharged particles.

Let's continue this line of inquiry. Earlier I have said that it is the helicity of Dirac-tachyon states that designates the naming of particle vs anti-particle; and there has been some uncertainly about whether this is a Lorentz invariant rule. Here is a short table of simple calculations of the scalar and the pseudoscalar forms for an ordinary Dirac wavefunction ψ_o and for a tachyon Dirac wavefunction ψ_t, both sensibly normalized.

$$\begin{array}{lll} \mathit{Scalar} & \bar{\psi}_o\psi_o = \omega/|\omega| = \pm 1 & \bar{\psi}_t\psi_t = 0 \\ \mathit{Pseudoscalar} & i\bar{\psi}_o\gamma_5\psi_o = 0 & i\bar{\psi}_t\gamma_5\psi_t = -h = \pm 1 \end{array} \tag{0.5}$$

That speaks well for using helicity, h, for tachyons as we use the sign of the frequency for ordinary Dirac particles.

There is more we might say. In the classical theory for tachyons I have written an additional factor $\zeta = \pm 1$ in front of the Lagrangian density.

$$\zeta m \int d\tau \sqrt{\epsilon\dot{\xi}^\mu\dot{\xi}^\nu g_{\mu\nu}}\, \delta^4(x - \xi(\tau)); \tag{0.6}$$

and I have said elsewhere that this sign factor should be the helicity of the particle state. That makes this expression a pseudoscalar, which aligns with the previous discussion.

References

[1] I recommend the review article by E. Recami, "Classical Tachyons and Possible Applications," Rivista del Nuovo Cimento, Vol. 9, N. 6 (1986); especially Chapter 9.

[2] Charles Schwartz, "Tachyons in General Relativity," *J. Math. Phys.* **52**, 052501 (2011)

[3] Charles Schwartz, "Toward a quantum theory of tachyon fields," *Int. J. Mod. Phys. A* **31**, 1650041 (2016)

[4] Charles Schwartz, "Revised Theory of Tachyons in General Relativity," *Mod. Phys. Lett. A* **32**, 1750126 (2017)

[5] Charles Schwartz, "Tachyon Dynamics - for Neutrinos?", *Int. J. Mod. Phys. A* **33**, 1850056 (2018)

[6] Charles Schwartz, "An Approach for Modelling Tachyons with Gravitation", *Int. J. Mod. Phys. A* **34**, 1950103 (2019)