

4.7: Tachyons and Faster-than-Light (FTL)

Learning Objectives

- Explain faster-than-light (**FTL**, superluminal) motion in relativity

A Defense in Depth

Let's summarize some ideas about faster-than-light (**FTL**, superluminal) motion in relativity:

1. Superluminal transmission of information would violate causality, since it would allow a causal relationship between events that were spacelike in relation to one another, and the timeordering of such events is different according to different observers. Since we never seem to observe causality to be violated, we suspect that superluminal transmission of information is impossible. This leads us to interpret the metric in relativity as being fundamentally a statement of possible cause and effect relationships between events.
2. We observe the invariant mass defined by $m^2 = E^2 - p^2$ to be a fixed property of all objects. Therefore we suspect that it is not possible for an object to change from having $|E| > |p|$ to having $|E| < |p|$.
3. No continuous process of acceleration can bring an observer from $v < c$ to $v > c$ (see section 3.3). Since it's possible to build an observer out of material objects, it seems that it's impossible to get a material object past c by a continuous process of acceleration.
4. If superluminal motion were possible, then one might also expect superluminal observers to be possible. But **FTL** frames of reference are kinematically impossible in $3 + 1$ dimensions (section 3.8).

Thus special relativity seems to have a defense in depth against superluminal motion.

Based on 2, **FTL** motion would be a property of an exotic form of matter built out of hypothetical particles with imaginary mass. Such particles are called tachyons. An imaginary mass is not absurd on its face, because experiments directly measure E and p , not m . E.g., if we put a tachyon on a scale and weighed it, we would be measuring its mass-energy E .

The weakest of these arguments is 1, since as described in section 2.1, we have no strong reasons for believing in causality as an overarching principle of physics. It would be exciting if we could detect tachyons in particle accelerator experiments or as naturally occurring radiation. Perhaps we could even learn to transmit and receive tachyon signals artificially, allowing us to send ourselves messages from the future! This possibility was pointed out in 1917 by Tolman¹ and is referred to as the "tachyonic antitelephone."²

If we're willing to let go of causality, then we just need to make sure that our tachyons comply with items 3 and 4 above. Argument 4 tells us that the laws of physics must conspire to make it impossible to build an observer out of tachyons; this is not entirely implausible, since there are other classes of particles such as photons that can't be used to construct observers.

Experiments to search for tachyons

Experimental searches are made more difficult by conflicting theoretical claims as to whether tachyons should be charged or neutral, whether they should have integral or half-integral spin, and whether the normal spin-statistics relation even applies to them.³ If charged, it is uncertain whether and under what circumstances they would emit Cerenkov radiation.

The most obvious experimental signature of tachyons would be propagation at speeds greater than c . Negative results were reported by Murthy and later by Clay,⁴ who studied air showers generated by cosmic rays to look for precursor particles that arrived before the first photons.

One could also look for particles with $|p| > |E|$. Alvager and Erman, in a 1965 experiment, studied the beta decay of ^{170}Tm , using a spectrometer to measure the momentum of charged radiation and a solid state detector to determine energy. An upper limit of one tachyon per 10^4 beta particles was inferred.

If tachyons are neutral, then they might be difficult to detect directly, but it might be possible to infer their existence indirectly through missing energy-momentum in reactions. This is how the neutrino was first discovered. Baltay *et al.*⁵ searched for reactions such as

$$\bar{p} + p \rightarrow \pi^+ + \pi^- + t \quad (4.7.1)$$

with t being a neutral tachyon, by measuring the momenta of all the other initial and final particles and looking for events in which the missing energy-momentum was spacelike. They put upper limits of $\sim 10^{-3}$ on the branching ratios of this and several other

reactions leading to production of single tachyons or tachyon-antitachyon pairs.

For a long time after the discovery of the neutrino, very little was known about its mass, so it was consistent with the experimental evidence to imagine that one or more species of neutrinos were tachyons, and Chodos *et al.* made such speculations in 1985. A brief flurry of reawakened interest in tachyons was occasioned by a 2011 debacle in which the particle-physics experiment OPERA mistakenly reported faster-than-light propagation of neutrinos; the anomaly was later found to be the result of a loose connection on a fiber-optic cable plus a miscalibrated oscillator. An experiment called KATRIN, currently nearing the start of operation at Karlsruhe, will provide the first direct measurement of the mass of the neutrino, by measuring very precisely the maximum energy of the electrons emitted in the decay of tritium, ${}^3\text{H} \rightarrow {}^3\text{He} + e^- + \bar{\nu}_e$. Conservation of energy then allows one to determine the minimum energy of the antineutrino, which is related to its mass and momentum by $m^2 = E^2 - p^2$. Because m^2 appears in this equation, the experiment really measures m^2 , not m , and a result of $m^2 < 0$ would bring the tachyonic neutrino back from the grave.

Tachyons and Quantum Mechanics

When we add quantum mechanics to special relativity, we get *quantum field theory*, which sounds scary and can be quite technical, but is governed by some very simple principles. One of these principles is that “*everything not forbidden is compulsory*.” The phrase was popularized as a political satire of communism by T.H. White, but was commandeered by physicist Murray Gell-Mann to express the idea that any process not forbidden by a conservation law will in fact occur in nature at some rate. If tachyons exist, then it is possible to have two tachyons whose energy-momentum vectors add up to zero. This would seem to imply that the vacuum could spontaneously create tachyon-antitachyon pairs. Most theorists now interpret this as meaning that when tachyons pop up in the equations, it’s a sign that the assumed vacuum state is not stable, and will change into some other state that is the true state of minimum energy.

References

¹ www.archive.org/details/theoryrelativmot00tolmrich

² Bilaniuk et al. claimed in a 1962 paper to have found a reinterpretation that eliminated the causality violation, but their interpretation requires that rates of tachyon emission in one frame be related to rates of tachyon absorption in another frame, which in my opinion is equally problematic, since rates of absorption should depend on the environment, whereas rates of emission should depend on the emitter; the causality violation has simply been described in different words, but not eliminated. For a different critique, see Benford, Book, and Newcomb, “The tachyonic antitelephone,” *Physical Review D* 2 (1970) 263. Scans of the paper can be found online.

³ Feinberg, “Possibility of Faster-Than-light Particles,” *Phys Rev* 159 (1967) 1089, [http://www.scribd.com/doc/144943457/](http://www.scribd.com/doc/144943457/G-Feinberg-Possibility-of-Faster-Than-light-Particles-Phys-Rev-159-1967-1089) G-Feinberg-Possibility-of-Faster-Than-light-Particles-Phys-Rev-159-1967-1089

⁴ “A search for tachyons in cosmic ray showers,” *Austr. J. Phys* 41 (1988) 93, <http://adsabs.harvard.edu/full/1988AuJPh..41...93C>

⁵ *Phys. Rev. D* 1 (1970) 759

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