The tachyon problem

In fact, the tachyon dooms string theory. Tachyons destabilize the vacuum, and you can't build a universe on an unstable vacuum. It's like trying to build a castle on sand. We have to get rid of tachyons.

In this chapter, we'll show why there are tachyons in the spectrum of an open string. Later, we'll figure out how to get rid of them,

Mass-less particles, like the photon, have only two spin states, up or down (or alternatively right-handed or left-handed spin). Massive particles are allowed three (or more) spin states, e.g. up, down, or zero spin.
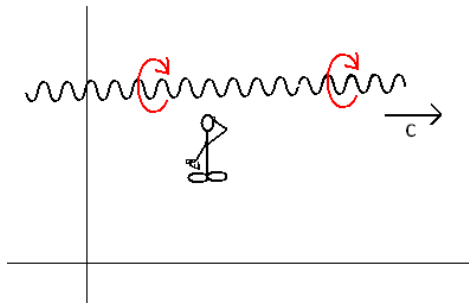

Figure 7.1. Observer sees photon approaching from the left has clockwise polarization, but same photon receding to the right has counterclockwise polarization. Observer could keep pace with a massive particle and would see zero spin polarization.

Here's why. Mass-less particles always travel at the speed of light. They can never be brought to rest. Spin is a vector perpendicular to the particle's motion. An observer cannot travel at c alongside the particle, so the observer never enjoys a frame of reference in which the spin vector disappears.

So if we find a particle that has only two spin states, it must have no mass. The first energy level of an open string has only two spin states, so no mass. We demonstrate this as follows.

We represent the ground state, E_0 as $|0\rangle$. We have shown previously that $E_0 = m_0{}^2$. We create the first energy state with the creation operator $a_1{}^+$ (or $b_1{}^+$ if we choose to generate the first mode along the y-axis). The first energy level, then, is a mixed state comprising $(a_1{}^+ + ib_1{}^+)$ and $(a_1{}^+ - ib_1{}^+)$. There are only two of these mixed states (and only two pure states, for that matter). So the particle represented by the lowest energy level in the string spectrum must be mass-less.

Well, that's not so bad, we might think. Maybe it's the photon.

Problem is, we've just shown that the first energy level

$$E_1 = m_0{}^2 + 1 = 0 \tag{7.1}$$

We've created a particle that is one unit of energy above the ground state. Because it has only two spin states, it has zero mass, zero energy.

So in the ground state

$$m_0{}^2 = -1 \tag{7.2}$$

By our analysis, the ground state has imaginary mass and energy. The ground state is a tachyon.