Particles and polarization

Let's take a brief digression to consider particles and circular polarization. We've seen that polarization states help to distinguish between massive and mass-less particles. And we've claimed that the creator combinations

$$\left(a_1^+(R) + ib_1^+(R)\right)\left(a_1^+(L) + ib_1^+(L)\right)|0\rangle \tag{10.1}$$

$$\left(a_1^+(R) + ib_1^+(R)\right)\left(a_1^+(L) - ib_1^+(L)\right)|0\rangle \tag{10.2}$$

$$\left(a_1^+(R) - ib_1^+(R)\right)\left(a_1^+(L) + ib_1^+(L)\right)|0\rangle \tag{10.3}$$

$$\left(a_1^+(R) - ib_1^+(R)\right)\left(a_1^+(L) - ib_1^+(L)\right)|0\rangle \tag{10.4}$$

produce different kinds of particles. Why? How can we claim that these expressions describe particles? And what do the expressions tell us about the particles? Following is considerable speculation on my part, so beware. Makes sense to me, but maybe it doesn't hold up under more rigorous analysis.

Here's a short summary of the argument that follows. The combinations of operators with the $+$ signs, e.g. the red mix of operators $\left(a_1^+(R) + ib_1^+(R)\right)$ in (10.2) produces a state that adds one unit of angular momentum to the ground state. The combination of operators with the $-$ sign, e.g. the green mix in (10.2), takes away one unit of momentum. So state (10.1) carries two units of angular momentum; it's a graviton. State (10.4) carries minus two units of angular momentum – another graviton. States (10.2) and (10.3) carry zero net angular momentum. They are identified as the axion and dilaton, particles also found in various formulations of the Standard Model.

Here's the logic. The form of these polarization operators reduce to the complex representation. For example,

$$\left(a_1^+(L) + ib_1^+(L)\right) \tag{10.5}$$

might be written as $r(L)e^{i\sigma}$ where $a_1^+(L)$ is the component of the state vector along the real axis and $b_1^+(L)$ is the component along the imaginary axis.

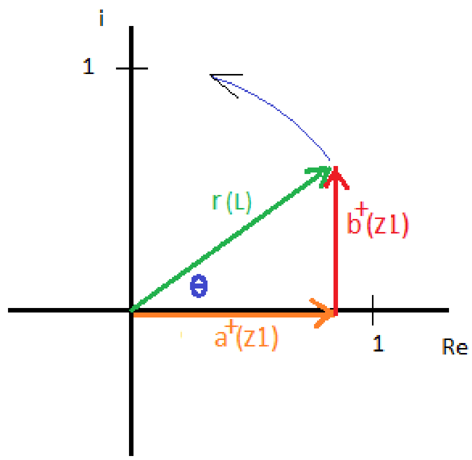


Figure 10.1. State vector representation of creation operators acting on the ground state. The operators a_1^+ and b_1^+ in our system are functions of position and momentum. z1 is a snapshot of the state at one position as the system is boosted down the z-axis. Curved blue arrow represents the $L-$ moving mode. Vectors are normalized such that their compositions always equal one.

Remember, the creation operators are functions of position and momentum.

$$a^+ = \left(\frac{\sqrt{n}x}{2} - \frac{ip_x}{\sqrt{n}}\right) \tag{10.6}$$

$$b^+ = \left(\frac{\sqrt{n}y}{2} - \frac{ip_y}{\sqrt{n}}\right) \tag{10.7}$$

Because of the momentum components, the creation operators will oscillate as the system moves along the $z-$ axis. The resultant sweeps out a circle; if we were observing the system from a perspective on the z-axis, we would see $L-$ circular polarization.

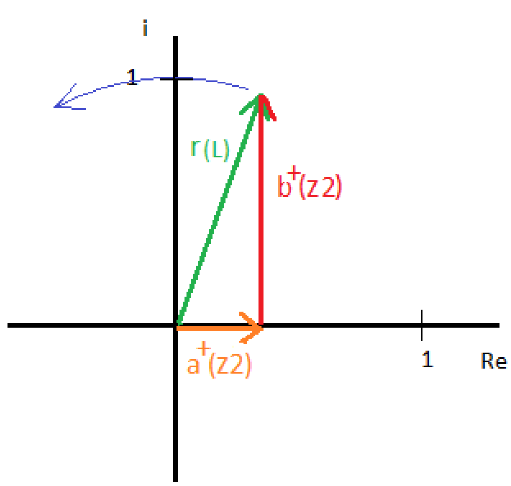
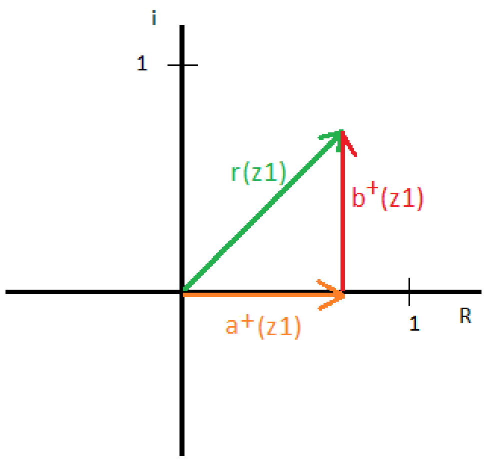


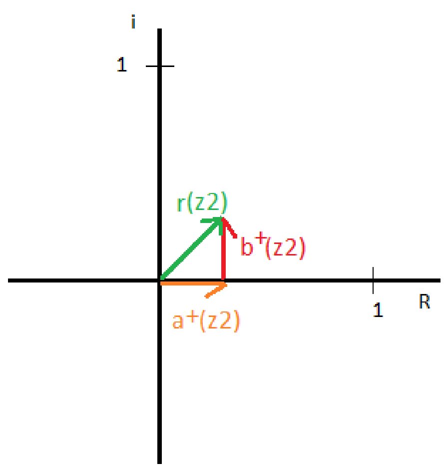
Figure 10.2. System at position z2.

If this was a photon, the resultant r would represent the electric field. On closed strings, r and its behavior define particle properties. If $a^+(z1)$ is shrinking while $b^+(z1)$ is stretching, or vice versa (as driven by their separate position and momentum components), r rotates in the direction shown by the blue arc. Over one complete cycle, r will rotate all the way around the origin. This is the complex representation of simple harmonic motion.

These are the conditions on state (10.1). State (10.4) behaves similarly, but rotates in the opposite direction. Only there's one further consideration. This circular polarization occurs twice on the same string, once for waves moving to the left and also for waves moving to the right. The effects are additive. Hence the two units of angular momentum. The graviton.

There's another possibility, expressed in states (10.2) and (10.3). We get different dynamics for r if a^+ and b^+ are in phase, i.e. if they are both shrinking or both stretching at the same time. In that case, r is locked along one or the other of the diagonals.





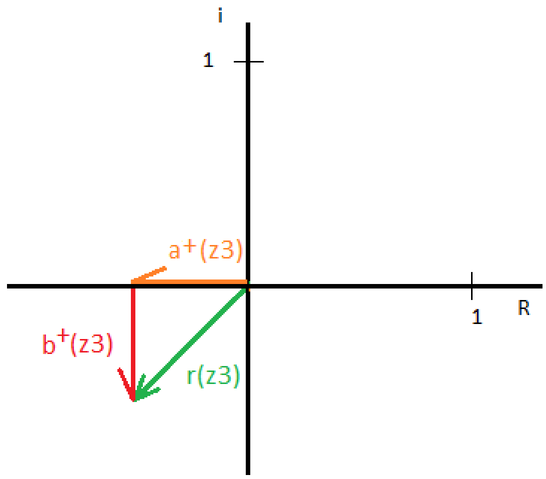


Figure 10.3. Resultant state vector oscillating along diagonal.

This particle has zero angular momentum. r does not rotate around the axis, but stretches and contracts along the diagonal. States (10.2) and (10.3) differ (perhaps) in that their resultants oscillate along different diagonals.

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