[SQUEAKING]

[RUSTLING]

[CLICKING]

MARKUS KLUTE: Welcome back to 8.701. So in this second chapter-- chapter number 1-- we start talking about quarks' and leptons' interactions and fields. And we start by a very general discussion of quantum fields and matter.

So you all know what we mean by particles and forces in the classical sense. However, we need now to see how they connect with quantum fields, and how this helps us to consider matter and forces in a very similar way.

The modern view of the basic way that particles come to exist is in terms of quantized fields, which is an extension of the quantum mechanics you love and know, which you have done before, where you quantize particles. These fields have quantum equations for their field amplitudes which are basically like the quantum simple harmonic oscillator, but there are an infinite number of them-- one for every possible frequency of wave in the field. This means the amplitudes for the wave for each frequency are therefore quantized in integer steps, just like in a simple harmonic oscillator.

This is what we see as a particle. The first excitation gives one particle of a frequency. The further excitation of the amplitude for the same frequency corresponds to two particles. Et cetera, et cetera. So hence, the concept of quantum field, unlike normal quantum mechanics, allows an arbitrary and changeable number of particles to exist. This is necessary, as you will see later, such that we can create and annihilate particles in reactions and decays. And the standard wavefunctions correspond to an equation of a particular frequency, amplitude when it exists in the [INAUDIBLE].

So now, just let's consider a few cases here. Imagine you have two particles-- two fermions, for example-- let's say two electrons. And you consider the wavefunction. Quantum field theory actually says that there's only one electron quantum field for the whole universe, and every electron which exists is due to an excitation of the field. Hence, all electrons are identical in the quantum-mechanical sense, as they all arise from the same field.

The theory says, then, that particular properties are the resulting wave equations-- namely, their symmetry-- and the exchange of these particles. So the extra symmetry depends on whether or not the particle is a fermion, which means it has spin 1/2 or 3/2 or 5/2, et cetera, or a boson, which means that it has spin 0, 1, or 2, and so on.

So for any identical fermion and electron, our quantum field theory says that their wavefunction must obey the property of antisymmetry. This means that when we write an overall wavefunction and we replace the particles, we pick up a minus sign.

This property is not just for electrons, but for all fermions-- that's all matter particle, as we saw last week. So it also holds for composite particles. A composite spin-1/2 particle is subject to the same antisymmetry.

This property of exchange antisymmetry leads to a well-known principle-- namely, the Pauli principle, which means that you cannot have two electrons of the same energy state or the same state, because when you would actually swap them, you find that they are identical, which is a stark contrast to the actual description of this wavefunction. So this doesn't really work. And therefore, two electrons, or two fermions, cannot be in the same state. [INAUDIBLE] very general.

Constructing a wavefunction or a total wave equation for two fermions is not that hard. We can simply do this by this construction.

An important additional statement or note to take here is that an antiparticle such as a positron is not identical to a particle, such as to the electron, again. If you move on to bosons, boson exchange is symmetric, meaning that if you [? request ?] two photons, you find the identical wavefunction. And then constructing a two-boson total wavefunction, you do this by adding those two functions together. This is, by definition, symmetric.

Let's look now forward to exchange particles. Again, you have a very good idea of the classical picture of how forces are transmitted. So the modern picture of how a force acts under quantization is by emission and by absorption of a particle. That is shown in this diagram here, where let's say you have an electron and a second electron. They see each other. And they see each other by emitting and absorbing photons. And you see this here. So this electron comes along, maybe emitting a photon. This electron [? readmits ?] it. And by this exchange of emission and absorption of photon, those two particles, the [INAUDIBLE] electrons to each other.

So this you can think about like two ships shooting cannons, if you want. But you also have to consider that there is not just repelling forces, but also attracting forces. We could have replaced the electron with a positron, and the negative and the positive charge would interact with each other.

This is it for this short-- it's basically an intro into the intro of the intro. I hope you enjoy this. All of those concept we go into more detail. This is really just the starting point. And then the next lecture, you'll see how we can actually understand aspects of this diagram here, which we call the Feynman diagram.