PROFESSOR: This is Louis-- L-O-U-I-S d-e Broglie. And this is not hyphenated nor together. They are separate. And the d is not capitalized apparently too. And it's 1924, the photon as a particle is clear, and the photon is also a wave.

And Louis de Broglie basically had a great insight in which he said that if this is supposed to be a universal or a real basic physical property that photons are waves and particles, we knew them as waves and now we know they're particles. But if they are dualed with respect to each other, both descriptions are in different regimes and in a sense, a particle at the end of the day has wave attributes and particle attributes. Wave attributes because it interferes and is described by waves. And particle attributes is because it has a definite amount of energy, it comes in packets, they cannot be broken into other things-- this could be a more general property.

And in a sense, you could say that de Broglie did a fundamental step almost as important as Schrodinger when he claimed that all matter particles behave as waves as well. Not just the photon, that's one example, but everybody does. So associated to every modern particle, there is a wave.

But that is quite interesting because in quantum mechanics, you have the photon and it's a particle, but it's associated to a wave and if you are a little quick, you say, oh sure, the electromagnetic wave, but no, in quantum mechanics, it's the probability amplitude to be some work. Those are the numbers we tracked in the mass and the interferometer, the probability to be sampled. We didn't track the waves or a single photon, the wave was a wave of probability amplitude, something they didn't know at all about yet at that time.

So de Broglie's says just like the photons have properties of particles and properties of waves, every particle has properties of waves as well and every wave has a property of particles. But what is left unsaid here is yes, you have a wave, but a wave of what? And we've already told you a little bit, the answer has to do with probability waves. So it's very strange that the fundamental equation for a wave that represents a particle is not an electric field or a sound wave or this, it's for all of them is a probability wave. Very, very surprising. But that's what de Broglie's ideas led to.

So if you had a photon, you would say it's a particle, and when you think of it as a particle, you would say it's a bundle of some energy and some momentum. And if you think of it as a wave, you would say it has a frequency. And that's a particle wave duality or in some sense, a particle wave description of this object-- you have a particle and a wave at the same time.

When we have this, we have a particle wave duality. And de Broglie said that this is universal for all particles. Universal. And it appeared the name of matter waves. These are the matter waves that we're going to try to discuss. These are the waves of something that are probability amplitudes we're going to try to discuss. So you could say wave of what? What. And that comes later, but the answer is probability amplitudes, those complex numbers whose squares are probabilities.

So just like we had for a photon, de Broglie's idea was that we would associate to a particle a wave that depends on the momentum. So remember, the Compton wavelength was a universal-- for any particle, the Compton wavelength is just one number, but just for photons, the wavelength depends on the momentum, so in general, it should be dependent on the momentum. So we say that for a particle of momentum p, we associate a wave-- a plane wave, in fact-- a plane wave, so we're getting a little more technical, with of lambda equals h over p, which is the de Broglie wavelength-- de Broglie wavelength.

So it's a pretty daring statement. It was his PhD thesis and there was no experimental evidence for it. It was a very natural conjecture-- we'll discuss it a lot more next lecture-- but there are very little evidence for it.

So experiments can a few years later, and people saw that you could interfere or diffract electrons. They would behave, colliding into lattices like waves, and those are rather famous experiments of Davisson and Germer. So particles, just like you do as an interference effect-- a two slit interference effect in which you have a screen, a slit and a screen, and you shine photons and then you get an interference effect over here because of the wave nature of photons, or in quantum mechanics, you would say, because there are probability amplitudes, that are complex numbers that have to be interfered between the possibilities of the two paths, because every photon goes through both paths at the same time, these experiments of interference, or two slit interference, were done for electrons.

And then, eventually, they've been done for bigger and bigger particles, so that it's not just something that you do with elementary particles now. There's experiments done about three years ago-- I will put on the web site or on the notes some of these things so that you can see them, but now you can throw in molecules here, molecules that have a weight of now 10,000 atomic mass units, like 10,000 protons, like hundreds of-- 430 atom molecules, and you can get an interference pattern, so it's pretty ridiculous. It's almost like, you one day so you throw a baseball and you're going to see an interference pattern, but, you know, we've got to things with about 10,000 hydrogen atoms and de Broglie wavelengths of 1 picometer, which are pretty unbelievable.

So the experiments are done with those particles and in fact with electrons. People do those experiments and they're in very beautiful movies in which you see those electrons hitting on the screen and then-- I'll give you some links so you can find them as well-- and you see one electron falls here and it gets detected and two electrons, three electrons, four electrons, five electrons, six electrons-- by the time you get 10,000 electrons, you see lots of electrons here, very well here, lots of electrons here, and the whole interference pattern is created by sending one electron at that time in an experiment that takes several hours and it's reduced to a movie of about one minute.

So particles, big particles interfere, not just photons interfere. So those particles have some waves, some matter waves discovered by de Broglie, and next lecture, we're going to track the story from de Broglie to the Schrodinger equation where the nature of the wave suddenly becomes clear.