Hello and welcome to Quantum Stories. A three-part mini-series explaining aspects of quantum mechanics at a simple level as part of Explorathon 2021. Episode 2, call a particle a particle. Last episode, we had a bit of a history lesson on the origins of quantum mechanics.

In this episode, we will explore the concept of wave particle duality. This concept is at the core of many introductory classes to quantum mechanics. It is often one of the first concepts introduced to those new to quantum mechanics.

There's a simple reason why is a popular first concept to tackle. And in my opinion, that is it's just really weird. It goes against almost everything we experience in our everyday life. I mean, a particle is a particle, like a spade is a spade.

Well, as we all realise at some point in our lives, things are not as black or white as they seem. The world is nuanced. Part one: What is a wave? A wave is a propagating disturbance. The classic examples are sound and water waves, but light is also wave.

Two key concepts characterise waves. One is noticeable in our everyday lives. Waves are spread out. If you generate some waves, say, by throwing a stone in a body of water, then you'll see those waves spread. In the case of the stone they spread out until the peak is so weak that the wave just no longer exists.

This is the same story somewhat for sound. It's what makes it possible to hear someone speaking around the corner. It's why light spreads out from the sun or a light bulb. The second more intricate key nature of waves is that the interfere.

This is not too common am occurrence in our everyday lives, but you may well have observed it. If you got a friend to throw a stone into a body of water at the same time as you. Then you'll observe that the two waves produced from the two sources combine with each other. Where two peaks meet

you'll get a stronger peak. Where two low points, meat you'll get a lower point, and were a peak in a low point meet they'll cancel. This makes sense, the wave is just a ripple on the water. Two ripples cannot move through each other without being affected by the other.

There are many more properties and intriguing things about waves. But these two points will be sufficient for us to continue with our story. Part two: What is a particle? I've recently been watching, like most people, the US Open and the amazing events that took place there.

And I think of particles and waves somewhere as two tennis players. Waves like you've just seen are the tactical players, full of finesse, spreading their shots around the court. Particles are the hard hitters. They do not care for finesse. They know where they want to go with the ball and they will make it go there.

Particles are very much the objects that surround us every day. The stereotype of a particle is a ball. Now, a ball does not spread out and move in all directions like the waves. It sits where you placed it. Assuming the surface is flat, that is.

If we hit the ball by, say, kicking it, then it moves in a single direction with an energy given to it by the kick. It doesn't spread out like the wave. The energy of the wave we talked about before was spreading out as the wave was spread.

If two balls meet, then you do not combine into one "Super Ball" like the waves. As interesting as that would be. Instead, the two balls collide and they will scatter off each other with the balls imparting their momentum to each other.

This is all true even for microscopic particles. A great example is the electron that makes up part of atoms and is the distributor of electricity. An electron, when given a push, will move in a single direction. Two electrons will collide and scatter from each other when they meet.

All sounds great. That sounds like our balls in this picture we had before. So we have particles and waves. Part 3: wave particle duality. As could be expected, this is not the full story. The famous example of the issue at hand is the double slit experiment, which was first performed by Thomas Young in 1801.

Young took a sheet with two narrow slits in it, spaced not too far apart and set up a light on one side, and the slits and a screen on the other. When light was shone on these slits, a pattern of light and dark patches would appear on the other side upon the screen.

This was the result of the two phenomena we talked about for waves. The light was spreading on the other side of the sheet from the two narrow slits. You could think of those two narrow slits being like the centre of where you threw your stone into the body of water.

When the light spreads out, it has peaks and low points. Now, each of these two slits has waves spreading out from them, with peaks and low points. These interfere causing the pattern on the screen. Now, imagine the same experiment, but instead of a light source, you have a source that is emitting electrons. When we cover up one of

the slits, the electron just goes through the remaining slit. And are simply incident on the screen on the other side opposite that slit. But when we allow both slits to be present, we observe that the electrons passing through the slits form the same interference pattern that we just seen with the light.

But this makes no sense. The interference pattern was because the wave nature of light, it was the result of the wave passing through both slits. But the electron is a particle, not a wave. It can only move through a single slit,

not both, right? Well, this imaginary experiment is very much true. It can be observed, and it was first performed in a not too dissimilar way in 1927 by Clinton Davisson and Lester Germer, and also independently by George Thompson in our very own Aberdeen.

This observation of an interference pattern of electrons can in no way be explained by the normal idea that particles move in paths. Instead, it means that particles must be able to be described as waves. They must spread out.

Part 4: de Broglie wavelength. In 1924, before the experiments we just discussed, French physicist Louis de Broglie formed the now famous de Broglie hypothesis. The de Broglie hypothesis says that all matter has wavelike properties. The classic characteristic of a wave is its wavelength.

The wavelength is the distance between two peaks of a wave. De Broglie set out rearranging some of the equations from the findings of the quantisation of radiation that we discussed in our origin of quantum mechanics last episode. He found that a particle

could have a wavelength as well. And he found this was equal to the Planck's constant we brought up last episode divided by the momentum of that particle. It is also true that most waves can be described by a wave equation.

We have mentioned one before in Maxwell's equations. And using this fact, Erwin Schrodinger managed to write a wave equation for matter in 1926, the famous Schrodinger equation, which is the building block of a large portion of modern quantum physics and dominates my everyday working life.

But let's not get too far ahead of ourselves down that storyline. Let's take a step back and think for a moment. I have just said all matter has wavelike properties and all matter has a wavelength. Much the same as a wave on the water has a wavelength between the two peaks, I'm saying that these electrons that we talked

about before have a wavelength. But these electrons are particles analogous to these balls that we were talking about before. So the balls have a wavelength? If the seat you are sitting on, the shoes, you're walking in, or the balls we were colliding before all have wave properties and a wavelength,

then why are they not all spreading out and interfering? Well. There's two schools of thought on that, and I can't really comment on which one is correct or not. We don't really know yet. One is simple. If we take the momentum of a normal object, it is far bigger than the Planck's constant.

So, this means the wavelength for that object is incredibly tiny. Not just tiny too. Smaller than anything we know of or can measure. So here's the second school of thought, if we cannot measure it and it is smaller than anything else we know,

is it real? So that's the case for normal, everyday objects, but we've already seen that microscopic particles like this electron can have wavelike properties. The wave particle duality of smaller particles like electrons is really an observable. The wave nature of microscopic particles has actually been observed for much larger objects, including large molecules.

I think the current record is a molecule made up of about 2000 atoms. That is a lot bigger than a single electron. But a lot smaller than the everyday objects that surround you. That is the end of our glimpse into wave particle duality.

Join us next episode as we move on to some more quirks of quantum mechanics. We will explain how particles could be in two states at once and what Einstein meant by a spooky action at a distance. I would like to thank the Explorathon team at the University of Strathclyde for their support in attempting this small mini

series. I would like to thank you for listening and hope you will join me again in the future.