So why...

So why is the fact that an electron is a wave, why is that so important?

Well, first of all, because it sets up this detective story of the electron set up this new theory that's coming, quantum mechanics, right?

But also, it immediately, just like we started painting with them, right-- remember that was one of my why this matters-- we also realized that we could see with them.

We could see with electrons.

Because if electrons are waves, then I can shine them just like I shine light and see what it shows me, right?

It can illuminate matter.

So if you look at the frequency here of light, this is an electromagnetic spectrum-- radio, microwave, infrared, visible, UV.

Now, here's the thing.

If you want to see something, some feature size, you're limited by the wavelength of the light.

It can't be bigger than the features you're looking at, roughlyish, OK?

That's what you'll-- so if you're trying to see something tiny, but the wavelength of light is really big, you won't see it.

So we need-- let's say we want to see atoms.

Let's say we want to see atoms, or even more, nuclei.

Look at how tiny.

Those are 10 to the minus n, 10 to the minus 12 meters.

Those are x-rays or gamma rays.

But the problem is, if we shine x-rays on things-- and we will do that when we look at crystals-- but if we shine x-rays, it's very hard to then collect them and make a photographic image, OK, at least one that gets you that resolution.

And gamma rays are even harder to catch, all right?

But see, here's the thing.

The electrons give you exactly what you need.

Because if we do this math for an electron-- so bring this one back down-- if we do this math for an electron, well, I'm going to use-- oh, I thought I had the middle one.

So if I have an electron-- let's suppose I have an electron that is-- electron, I'm going to say I accelerate it over 100 volts.

I'm going to take an electron, and I'm going to put it over 100 volts.

I'm going to give it some kinetic energy, right?

So it's kinetic energy is then going to equal 100 eV, right?

OK, so now I've got an electron moving with a kinetic energy that's 100 eV.

Now you can convert this to joules, and you can set this equal to 1/2 mv squared, right, mass of the electron times its velocity squared.

And then once you have the velocity, so you get the V.

And then once you have that, you get the momentum, the p, right?

And then once you have that, you get the wavelength, right?

So I can go now from something that's easy to do.

100 volts is a lot, but in a lab safe, not in your dorm.

You could apply 100 volts to an electron, get it going at this speed.

And once you know the speed, you know the momentum.

And if you know mv, then you know it's wavelength.

In that case from this relationship, you would get that it's about 0.12 nanometers.

But look at this.

The wavelength of a simply accelerated electron is right where I need it.

It's right where I need it.

It's an Angstrom, right?

So now, if I take advantage of the wavelengths of the wave nature of electrons and I shine them on materials, then I can see materials that way.

And I can see them at that scale.

And we do that all the time, all the time in many, many different areas of technology and research today.

We use electrons to image.

In fact, the best images you can get are made with electrons, all right?

Here's an example of using what's called a scanning electron microscope, all right?

So you see a butterfly, but you want to really see a butterfly, or we can go even further.

And instead of just drawing pictures of this these beautiful materials made of carbon-- those are called nanotubes.

This is called graphene.

Gesundheit.

It's a single sheet of carbon atoms, one atom thick material.

Notice with these materials every single atom is a surface atom.

That's pretty cool.

They also have lots of other cool properties.

And I'll give you examples throughout other lectures of how these kinds of materials can be used.

But for now, I'm talking about seeing them.

And this is what happens when you actually look at them with an electron.

That's a nanotube.

And here is a picture of graphene.

The only reason we can see graphene is because we have electrons.

And we take advantage of the wave nature of those electrons.

Well, you say, well, OK.

But why does that matter?

Well, that matters tremendously, because one of the first experiments that really did what Feynman, what Richard Feynman wanted-- Richard Feynman predicted the field of nanotechnology 50 years ago.

He gave a famous speech at Caltex called There's Plenty of Room at the Bottom.

He's also an amazing teacher, and he taught actually the double slit experiment.

I highly recommend you Googling that lecture.

And he said that someday, you can put the atom where you want, all right?

And the first time that was done was in 1989 by IBM.

They had 35 xenon atoms.

They moved them around.

But the point is, you couldn't realize nanotechnology.

You couldn't realize the ability to actually move atoms if you can't see them, right?

And this, the ability to see what you were doing changed everything.

It changed everything.

And nature had been doing this.

And I love these examples.

So nature has been doing nanotech for a long time, all right?

So you have the inner ear of the frog.

It's a cantilever that is sensitive to a few nanometers of movement.

The frog can actually hear that.

You've got features in the ant's eye.

I love the silk moth.

The male silk moth has a single molecule detection system onboard that can sense a single molecule pheromone.

It can detect a female silk moth two miles away, two miles away.

We have nothing like that.

We have no technologies like that.

I can't even tell if someone's in the next room.

I have to look at my phone or something.

This is because of nanotechnology, that kind of detection system, all right?

But it was the ability to see atoms and molecules with electrons that kind of blew open this entire field, all right?

And it's made it so that we can now try at least to rival nature.

Here is one example.

You're not just seeing graphene, but check this out.

You're seeing a single atom of graphene, and you're seeing what happens under a certain kind of irradiation.

And you're seeing this hole.

And you're seeing the hole grow.

And that's really important, because something I care a lot about are membranes, right?

And another one of these matters, I'll tell you about membranes.

But here, I'm actually making the thinnest possible membrane that you could make because it's only one atom thick.

And I'm controlling how I make that.

But I would never know what my controls do if I couldn't see it in real time, all right?

So this is my why this matters.

It's seeing things at this scale.