## CONCEPTUAL QUANTUM MECHANICS:

It was Richard Feynman, one of the most important figures in the creation of quantum mechanics, who said, “I think I can safely say that nobody understands quantum mechanics.” This is because quantum mechanics is in such contrast with everyday experience, that it makes little sense. The theories of relativity, while confusing, can be understood logically. When you analyze relativity, you can see the inevitability of the conclusions. Quantum mechanics is amazingly different. Few people can understand why it is that things happen within the theory. It is primarily a theory of equations that work in real life, but make little sense when you try to rationalize them.

Despite this, the theory can be described as it is, even if we can’t always see why this is the way things are.

## GRAINY ENERGY:

Max Planck first proposed the idea as a solution to a problem with Maxwell’s theories about electromagnetic radiation. The problem arises when matter absorbs and releases energy. For example, if you held a brink under a flashlight, the brick should absorb the energy of the flashlight, and re-emit it back out. The problem comes in describing how this energy is re-emitted. According to Maxwell’s equations, it could come out in the form of a wave with a large amplitude and a long wavelength, or as a small amplitude with a small wavelength. In fact, it could come back out as one of an infinite set of wave patterns.

In other words, an infinite amount of energy would supposedly come out of the brick.

Clearly, this is impossible. And it spells the downfall of classical physics. This is where Max Planck comes into play. He realized that if he limited the energy to whole numbers of an “energy denomination”, no fractions allowed, and set this “energy denomination” so that it was dependant on the wavelength, the impossible number of infinite wavelengths was eliminated. In other words, a ray with a very small wavelength wasn’t allowed to carry a small enough energy to equal the energy put in by the flashlight. By turning energy from a continuous scale to a scale of lumps, he had fixed classical physics.

But nobody could tell why this concept should have worked. Nobody until Einstein pondered something called the photoelectric effect. When light is shone on certain materials, the electrons are ejected from the material. This isn’t surprising. But on closer analysis, it gets stranger. You would think that the brightness of the light would increase the speed the electrons are ejected. This, however, doesn’t happen. Instead, only increasing the frequency (lower the wavelength to increase the wave’s energy) would the electrons move faster. In fact, even if the light is blindingly intense, if the frequency is too low the electrons won’t even eject.

Einstein’s solution was that light came in packets, and that each electron could only absorb one of these packets. If the frequency of that particular packet was too low, the electron wouldn’t eject, even if it was bombarded by thousands of these packets.

It became quite simple. The number of electrons ejected depended on the intensity because intensity was the number of these energy packets. The speed of the electrons ejected depended on the frequency because the frequency determined how much energy each individual electron would collect from this energy packet.

Today, we call these energy packets photons, or particles of light.

WAVE PARTICLE DUALITY:

Things get stranger when the details are analyzed, however. Because light doesn’t behave as though it is composed of tiny particles, it behaves as though it is a wave. It gets worse. Even electrons, and other particles of mass, behave as though they are waves, even though they are actually particles. Or are they?

The double-slit experiment is a good example of this strangeness. When you shine a light through a single slit onto a sheet of paper, you find what you expect, a solid bar of light on the paper. You can imagine this as photons getting blocked by the sides of the slit, some going through, and impacting the paper. This makes sense.

If you put two slits next to each other, though, you find an interference pattern on the piece of paper, a series of blurred bars and shadows. When you think of light as a wave, this isn’t surprising, as it isn’t hard to imagine waves interfering with each other. But if you think of it as particles, it gets harder to imagine. Still, you can rationalize it. Since every photon supposedly has its own frequency, they could still conceivably interfere with each other to create the same image.

You knew this was coming: it gets stranger. In more recent experiments, we have replaced the light source with a source that allows only one photon through at a time. And we have replaced the paper with a material that glows whenever it comes in contact with a single photon.

We find that if we let the photons through one at a time, with no other photons to interfere with, and let these photons hit the material at the other side until it builds up an image, we find the EXACT SAME interference pattern. Same with electrons, particles of mass.

What on Earth could these photons be interfering with?

THE UNCERTAINTY PRINCIPLE:

The strangeness continues, as we realize that when things are this small, they don’t have a defined position or speed. This is confusing at the least. But it makes sense. If you wanted to see an electron, you would have to see it with a photon. But if you hit it with a photon, you have completely changed its position and velocity. This was noticed by Werner Heisenberg in 1927.

He noticed that understanding of position and velocity were inversely proportional to each other. This is because in order to pin down the location of the electron, you have to use a tighter frequency (you can only know the position of the electron to an accuracy equal to that of the wavelength) which in turn strongly disturbs the electron's velocity. In other words, you can never define the exact position and velocity of a subatomic particle. You can only define the probability of either value.

Ultimately, this explains the double-slit experiment. In that experiment, you don't know exactly where it is that the particle is, or how fast it's going. You can only define the probability of either value. In this way, the electron is more than a particle, it is a wave of probabilities.

So, what are the photons interfering with? It turns out, they are actually interfering with themselves. Each individual photon is interfering with ITSELF as it passes through BOTH slits in the experiment. The probability that the photon went through one slit interferes with the probability that it went through the other, and the interference pattern results from this.

As you can see, this answer defies all common sense. How can a particle interfere with itself? The particle either went through one slit, or the other. But this isn't so. You can't prove which slit the particle went through in any case. People have tried to formulate all sorts of explanations, including possibilities that other versions of the particle exist in a parallel universe, and that somehow those particles interfere with each other across universes.

But none of these answers is better than any other. All result in the same equations, and each makes less sense than the other. One is tempted to throw the equations out the window and claim that this can't reflect reality at all. But it describes actual results, actual experiments in the real world. This is the way the microscopic world works, completely different from the way our minds are built to understand the universe.

People are still looking for a way to describe quantum mechanics in a way that our minds can truly comprehend, wondering if the theory was discovered in such a way that the answers are correct, but through a framework that is incorrect. So far, nothing.

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