A Dive into Quantum Mechanics

Have you ever wondered about the laws that govern the subatomic world, the world of atoms and other tiny particles that make up all matter? Well then you will really be interested in quantum mechanics because it is the study of the crazy, awe-inspiring laws that control the world of subatomic particles. Even if you do not love science, I am sure it will fascinate you because it seems so impossible and unreasonable compared to the laws the govern the world around us. As Niels Bohr, a prominent theoretical physicist during the early 20th century said, "If quantum mechanics hasn't profoundly shocked you, you haven't understood it yet." Many of you may wonder why the laws of quantum mechanics are important, and the answer is that the laws led to some of the most important inventions in history such as the microchip. Albert Einstein refused to believe many of the concepts because they seemed too out-there and farfetched. The purpose of this article is to make quantum mechanics accessible to everyone. It is also meant to show that thinking way out of the box can result in wonderful discoveries. My only advice is to be prepared to look beyond all of your preconceptions about the universe and come in with an open mind.

Wave-Particle Duality

The concept of the wave-particle duality states that subatomic particles can act as both waves and particles. Before you think about it too much, let me tell you about Young's Double Slit Experiment that proved this concept. First, imagine you have a surface with two slits suspended over a surface with no slits. If you pour sand over the two slits, then the sand piles up directly below each slit (**Figure 1**). Now let's scale down the experiment to a subatomic level, in which individual particles are shot at a surface with one slit with a material behind it that

Figure 1

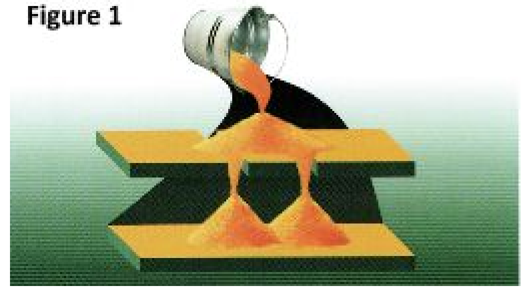
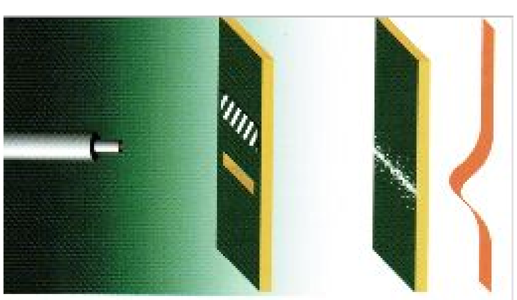


Figure 2



senses where the particle hits (**Figure 2**). When we conduct this experiment, the particles land directly behind the single slit like in the example with the sand. If we repeat this experiment with two slits then the particles act quite differently. The particles hit in multiple locations, the most common being directly in between the two slits (**Figure 3**). Why do the particles act like this? Well, if you imagine two waves going through the slits then the interaction, or superposition, between the waves causes the the interaction of the wave to hit in the same locations that the particle did (**Figure 4**). This must mean that the particle turns into a wave and goes through both slits at once, and then it becomes a particle right before it reaches the back surface. When one observes this experiment using any means, the particle acts like a normal object; falling directly behind the slit (**Figure 5**). Thus when the experiment is not observed the particle acts like both a particle and wave, and when the experiment is observed, the particle acts simply like a particle; therefore, the act of looking at the experiment alters the behavior of the subatomic particles.

Figure 3

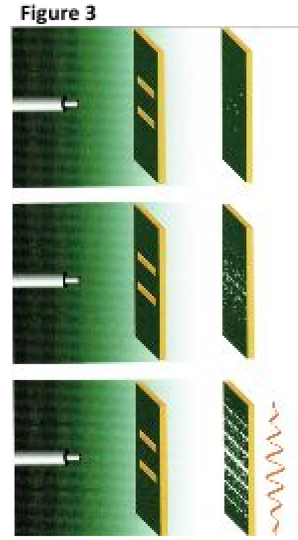
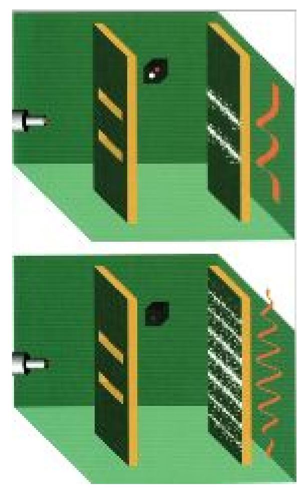


Figure 4

Figure 5



Quantum Entanglement

Quantum entanglement is one of the most fascinating and shocking theories in quantum mechanics. This subject is so unique that Albert Einstein called it, “spooky action at a distance.” Two subatomic particles become entangled, or “connected,” when they have any physical contact with each other. According to quantum mechanics, the particles are considered to be in all states simultaneously until they are observed. When the particles are observed, one particle will have either spin up or spin down. Instantly, the other particle displays the opposite spin; this instant reaction occurs over any distance; therefore, the particles must be communicating at speeds faster than the speed of light. Just to be clear, the spin being referred to is not conventional spin, like that of a top, but instead it is quantum spin. In quantum mechanics spin refers to characteristics like the angular momentum of the particle. Einstein completely rejected the idea that the particles were communicating at speeds greater than the speed of light; he said that the particles were pre-programmed with their spin. He compared this to the left glove and right glove that make up a pair of gloves. John Bell, an experimental physicist, conducted an experiment in the late 20th century that proved Einstein wrong, which came as a shock to many. Quantum entanglement can be used to develop many futuristic technologies such as quantum computing and quantum teleportation.

Heisenberg's Uncertainty Principle and Indeterminacy

Another fundamental and import topic in quantum mechanics is the concept of indeterminacy. Indeterminacy states that one can never know everything about a quantum state, even if they are able to measure it. The most widely known example of this is Heisenberg's Uncertainty Principle. This principle states that we can never accurately know both the position and velocity of a subatomic particle. For example, the more accurately we know the position, the less accurately we know the velocity. It is quite like the optical illusion that shows two faces and a vase, in which you cannot clearly look at both of them at the same time (**Figure 6**). An example of the uncertainty principle in practice is when one attempts to measure the position and velocity of a particle using light. Some waves of light will scatter when they hit the particle, therefore indicating the position. However, the accuracy of this measurement is only as accurate as the distance between each crest of the light waves. Thus, one needs to use light with short wavelengths, which has a higher frequency, to measure the position of the particle accurately. The higher the frequency, or number of wavelengths that occur in a given time, the more energy the light has. It follows that the higher the frequency of light the more it disturbs the particle it hits. This

Figure 6

disturbance affects how accurately we can measure the velocity of the particle. On the other hand, if one uses a lower frequency of light, it will allow the velocity to be measured more accurately, but the position will be measured less accurately.

Schrödinger’s Wave Function

Erwin Schrödinger, a theoretical physicist in the early 20th century, created an equation that describes how a subatomic particle evolves over time. Solving the equation provides a mathematical property called the wave function. For example, the wave function does not provide the exact position of a particle like an electron, but instead it provides the region where an electron can be found at a given time. The wave function is spread out over all space like a wave, yet one should not think of the wave function as a wave. Instead, it is generally accepted to think of it as a mathematical concept that when solved has concrete results. A real world example of the wave function is if a prisoner escaped from jail. After a short period of time it is possible that he traveled a certain distance away from the jail, but it is most likely that he is near the jail. A wave function could be used to assign a probability of the criminal being in a certain location. It is important to point out that wave functions can interact with each other and that they can describe characteristics other than position.

Schrödinger’s Cat

Schrödinger’s cat is a thought experiment devised by Erwin Schrödinger. It is important to note that this would not happen in real life; instead, Schrödinger is using a common object to help convey what happens when a quantum system is not observed, and what happens as a result of observing a quantum system. In the experiment, a cat is put in a box with a lethal poison and a radioactive nucleus. The particle emitted by the nucleus would trigger an administering of the lethal poison, thus killing the cat. The moment that a radioactive nucleus decays is an event that cannot be predicted exactly. Instead, there is a certain probability that the nucleus will decay at a certain time. The future of the nucleus can be described by a wave function with two parts: decayed nucleus and non-decayed nucleus. Schrödinger went on to propose that because the cat is made up of atoms its future too can be described by a wave function. The cat's wave function also has two parts: dead cat and live cat. Now let's go back to the double slit experiment; remember how the particle did not act like a wave when when observed. The act of looking at the system influenced the outcome; this also applies to Schrödinger's Cat. Before being observed the cat is considered to be in all states, just like an entangled particle is considered to be in all states before it is observed. This means that the cat must be both dead and alive! The act of observing the cat causes the cat to instantly adopt one of these states, being dead or alive. Therefore, the act of looking at the cat either kills or saves the cat.

Conclusion

Although all of this may seem a little pointless to you, the laws of quantum mechanics are fundamentally important to the universe and its behavior. Furthermore, it shows us that challenging our preconceptions and thinking completely out of the box can be not only correct, but extraordinarily beneficial to the world!

Sources:

I. Information

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II. Graphics

A. Angel, David. *Pieces for Quantum: A Guide for the Perplexed*. 2003. Graphic Design. London.