The New Quantum Mechanics

Skills to Develop

- Describe some of the contributions of de Broglie and Heisenberg to "new quantum mechanics"

The "New Quantum Mechanics" was introduced a little after the "Old Quantum Mechanics" which was developed by Planck and Bohr. This is when quantum mechanics became very confusing to people. In the old quantum theory, we could think about particles moving in normal ways. The electrons orbit the nucleus just like planets orbit the sun. But this was wrong. The new quantum theory says that tiny particles behave in ways that are totally different from normal objects that we can see, like basketballs or planets. In fact, it is impossible to know exactly where they are or what they do.

Einstein had convinced physicists that light was a particle (now called photon) in 1905. Later in 1925, de Broglie proposed that particles like electrons could also be waves. De Broglie was a French prince who was initially interested in history, but during World War I he joined the army as a radio operator and became interested in waves. He was also a lover of music. These qualities lead him to interpret Bohr's atoms as "musical instruments." Bohr assumed that his energy levels were quantized, but didn't explain why. De Broglie proposed that quantization arose from the same effects as the quantized frequencies (fundamental and overtone) present in a guitar string, that make it work as an instrument. (Review standing waves in this section if needed.) De Broglie thought that electrons in "orbits" like in the Bohr model were like strings on instruments. A string has to have nodes at each end; an electron in an orbit also has to be a standing wave, with a whole number of wavelengths around its path. In other words,

$$n\lambda = 2\pi r \tag{1}$$

where n is an integer. Thus, the wave interferes constructively with itself when it makes a full circle.

According to his theory,

$$\lambda = \frac{h}{mv} \tag{2}$$

He derived this equation using the radii Bohr calculated for his orbits. You can see that the wavelength effect is only important for very small particles, like electrons (check this out for yourself!). He thought that the "wave-ness" of electrons would be present outside of atomic orbits as well, and this proved true. A beam of electrons accelerated by high voltage is predicted to have similar wavelength to X-rays, and like X-rays, can be diffracted by a crystal. The diffraction pattern let researchers measure the wavelength of electrons (whose velocity was known, because they were accelerated by a known voltage) just as Moseley had measured the wavelength of emitted X-rays to determine atomic numbers. Later the wavelengths of atoms were measured as well. The experimental wavelengths matched de Broglie's prediction, and the wave-particle duality for electrons was accepted, just like the wave-particle duality for light.

Heisenberg developed a way to work with the allowed energies of atoms using matrices. He believed that we must work with the quantities we can observe experimentally, like energies (via spectroscopy). This led him to the Uncertainty Principle which says that certain pairs of quantities (position and momentum, energy and time) can't be measured precisely at the same time. For instance, if you want to know exactly where a particle is, you can't also know exactly what its velocity is. This was part of the new "statistical" quantum mechanics. In classical mechanics, you can know everything about particles (like balls): exactly where they are, exactly where they are going, and predict exactly the results of collisions or other events. In the new quantum mechanics, it was argued that this perfect knowledge of particles was simply impossible. For instance, exactly where is a wave?

Although Heisenberg's matrix quantum mechanics is probably used more often because it works well with computer calculations, an equivalent description developed by Schrodinger gives more intuition, so we will describe it in detail. The methods give the same answers but use very different math. Schrödinger extended de Broglie's theory by applying well-known physics of waves (for instance, in instruments) to describe electrons. There's a detailed example in the next section.

Outside Links

- The Wave Behavior of Matter, by DCaulf (15 min)

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