The mathematical form of the uncertainty principle states that the product of the uncertainties in position and momentum will always be larger than some minimum value. Arguments similar to those given here show that this minimum value is Planck's constant (h) divided by 4π. Thus, $\Delta x \Delta p \geq \frac{h}{4\pi}$. In this equation, Δx and Δp represent the uncertainty in the measured values of a particle's position and momentum, respectively, at some instant. This equation shows that if Δx is made very small, Δp will be large, and vice versa.

THE ELECTRON CLOUD

In 1926, Erwin Schrödinger proposed a wave equation that described the manner in which de Broglie's matter waves change in space and time. Although this equation and its derivation are beyond the scope of this book, we will consider Schrödinger's equation qualitatively. Solving Schrödinger's equation yields a quantity called the *wave function,* represented by ψ (Greek letter *psi*). A particle is represented by a wave function, ψ, that depends on the position of the particle and time.

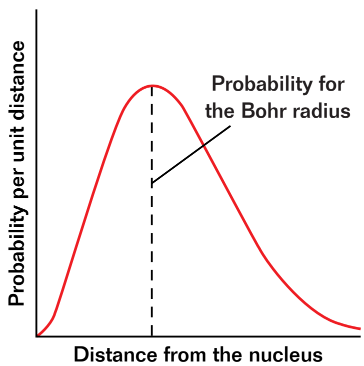

Figure 20
The height of this curve is proportional to the probability of finding the electron at different distances from the nucleus in the ground state of hydrogen.

An electron's location is described by a probability distribution

As discussed earlier, simultaneous measurements of position and momentum cannot be completely certain. Because the electron's location cannot be precisely determined, it is useful to discuss the *probability* of finding the electron at different locations. It turns out that the quantity $|\psi|^2$ is proportional to the probability of finding the electron at a given position. This interpretation of Schrödinger's wave function was first proposed by the German physicist Max Born in 1926.

Figure 20 shows the probability per unit distance of finding the electron at various distances from the nucleus in the ground state of hydrogen. The height of the curve at each point is proportional to the probability of finding the electron, and the x coordinate represents the electron's distance from the nucleus. Note that there is a near-zero probability of finding the electron in the nucleus.

The peak of this curve represents the distance from the nucleus at which the electron is most likely to be found in the ground state. Schrödinger's wave equation predicts that this distance is 5.3×10^{-11} m, which is the value of the radius of the first electron orbit in Bohr's model of hydrogen. However, as the curve indicates, there is also a probability of finding the electron at various other distances from the nucleus. In other words, the electron is not confined to a particular orbital distance from the nucleus as is assumed in the Bohr model. The electron may be found at various distances from the nucleus, but the probability of finding it at a distance corresponding to the first Bohr orbit is greater than that of finding it at any other distance. This new model of the atom is consistent with Heisenberg's uncertainty principle, which states that we cannot know the electron's location with complete certainty.

Did you know?

Although Einstein was one of the founders of quantum theory, he did not believe that it could be a final description of nature. His convictions in this matter led to his famous statement, "In any case, I am convinced that He [God] does not play dice."