

## 14.3: Proton NMR Spectrometers Operate at Frequencies Between 60 MHz and 750 MHz

In the mid 1920's the German physicist Werner Heisenberg showed that if we try to locate an electron within a region  $\Delta x$ ; e.g. by scattering light from it, some momentum is transferred to the electron, and it is not possible to determine exactly how much momentum is transferred, even in principle. Heisenberg showed that consequently there is a relationship between the uncertainty in position  $\Delta x$  and the uncertainty in momentum  $\Delta p$ .

$$\Delta p \Delta x \geq \frac{\hbar}{2} \quad (14.3.1)$$

You can see from Equation 14.3.1 that as  $\Delta p$  approaches 0,  $\Delta x$  must approach  $\infty$ , which is the case of the free particle discussed previously.

This uncertainty principle, which also is discussed in Chapter 4, is a consequence of the wave property of matter. A wave has some finite extent in space and generally is not localized at a point. Consequently there usually is significant uncertainty in the position of a quantum particle in space. Activity 1 at the end of this chapter illustrates that a reduction in the spatial extent of a wavefunction to reduce the uncertainty in the position of a particle increases the uncertainty in the momentum of the particle. This illustration is based on the ideas described in the next section.

### ? Exercise 14.3.1

Compare the minimum uncertainty in the positions of a baseball (mass = 140 gm) and an electron, each with a speed of 91.3 miles per hour, which is characteristic of a reasonable fastball, if the standard deviation in the measurement of the speed is 0.1 mile per hour. Also compare the wavelengths associated with these two particles. Identify the insights that you gain from these comparisons.

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