We distinguish between observing and probing. Consider a cup of coffee on the other side of a room. If you passively glance at it and see steam rising from it, this act of "measuring" involves no physical interaction between your eyes and the coffee. Your glance neither adds nor subtracts energy from the coffee. You can assert that it's hot with no *probing*. Placing a thermometer in it is a different story. You physically interact with the coffee and thereby subject it to alteration. The quantum contribution to this alteration, however, is completely dwarfed by classical uncertainties and is negligible. Quantum uncertainties are significant only in the atomic and subatomic realms.

Compare the acts of making measurements of a pitched baseball and of an electron. You can measure the speed of a pitched baseball by having it fly through a pair of photogates that are a known distance apart (Figure 31.13). The ball is timed as it interrupts beams of light in the gates. The accuracy of the ball's measured speed has to do with uncertainties in the measured distance between the gates and in the timing mechanisms. Interactions between the macroscopic ball and the photons it encounters are insignificant.

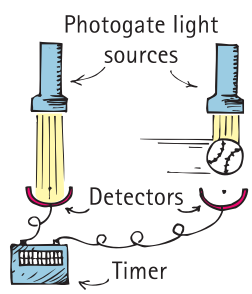

FIGURE 31.13
The ball's speed is measured by dividing the distance between the photogates by the time difference between crossing the two light paths. Photons hitting the ball alter its motion much less than the motion of an oil supertanker would be altered by a few fleas bumping into it.

But not so in the case of measuring submicroscopic things like electrons. Even a single photon bouncing off an electron appreciably alters the motion of the electron—and in an unpredictable way. If you wish to observe an electron and determine its whereabouts with light, the wavelength of the light would have to be very short. You fall into a dilemma. Light of a short wavelength, which can "see" the tiny electron better, corresponds to a large quantum of energy, which, in turn, greatly alters the electron's state of motion. If, on the other hand, you use a long wavelength that corresponds to a smaller quantum of energy, the change you induce in the electron's state of motion will be smaller, but the determination of its position by means of the coarser wave will be less accurate. The act of observing something as tiny as an electron probes the electron and, in so doing, produces a considerable uncertainty in either its position or its motion. Although this uncertainty is completely negligible for measurements of the position and motion of everyday (macroscopic) objects, it is a predominant fact of life in the atomic domain.

SCREENCAST: The Uncertainty Principle

The uncertainty of measurement in the atomic domain, which was first stated mathematically by the German physicist Werner Heisenberg, is called the **uncertainty principle**. It is a fundamental principle in quantum mechanics. Heisenberg found that when the uncertainties in the measurements of the momentum and position of a particle are multiplied, the product must be equal to or greater than Planck's constant, h, divided by 2π, which is represented as $\hbar$ (called *h-bar*).[4] We can state the uncertainty principle in a simple formula:

$$\Delta p \, \Delta x \geq \hbar$$

Werner Heisenberg (1901–1976)

[4]Quantum physicist Ken Ford celebrates $\hbar$ on the number plate of his Honda Civic Hybrid (see page 375).