EXAMPLE 5–9 **Ultracentrifuge.** The rotor of an ultracentrifuge rotates at 50,000 rpm (revolutions per minute). The top of a 4.00-cm-long test tube (Fig. 5–17) is 6.00 cm from the rotation axis and is perpendicular to it. The bottom of the tube is 10.00 cm from the axis of rotation. Calculate the centripetal acceleration, in "g's," at the top and the bottom of the tube.

APPROACH We can calculate the centripetal acceleration from $a_R = v^2/r$. We divide by $g = 9.80\,\text{m/s}^2$ to find a_R in g's.

SOLUTION At the top of the tube, a particle revolves in a circle of circumference $2\pi r$, which is a distance

$$2\pi r = (2\pi)(0.0600\,\text{m}) = 0.377\,\text{m per revolution.}$$

It makes 5.00×10^4 such revolutions each minute, or, dividing by 60 s/min, 833 rev/s. The time to make one revolution, the period T, is

$$T = \frac{1}{(833\,\text{rev/s})} = 1.20 \times 10^{-3}\,\text{s/rev.}$$

The speed of the particle is then

$$v = \frac{2\pi r}{T} = \left(\frac{0.377\,\text{m/rev}}{1.20 \times 10^{-3}\,\text{s/rev}}\right) = 3.14 \times 10^2\,\text{m/s.}$$

The centripetal acceleration is

$$a_R = \frac{v^2}{r} = \frac{(3.14 \times 10^2\,\text{m/s})^2}{0.0600\,\text{m}} = 1.64 \times 10^6\,\text{m/s}^2,$$

which, dividing by $g = 9.80\,\text{m/s}^2$, is 1.67×10^5 g's.

At the bottom of the tube ($r = 0.1000\,\text{m}$), the speed is

$$v = \frac{2\pi r}{T} = \frac{(2\pi)(0.1000\,\text{m})}{1.20 \times 10^{-3}\,\text{s/rev}} = 523.6\,\text{m/s.}$$

Then

$$a_R = \frac{v^2}{r} = \frac{(523.6\,\text{m/s})^2}{(0.1000\,\text{m})} = 2.74 \times 10^6\,\text{m/s}^2$$

$$= 2.80 \times 10^5\ g\text{'s},$$

or 280,000 g's.

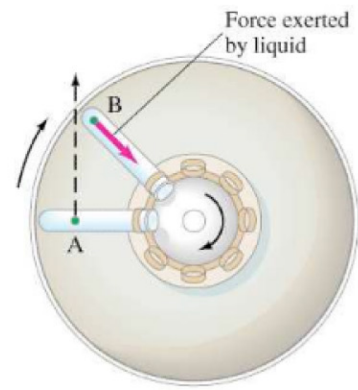

FIGURE 5–17 Two positions of a rotating test tube in a centrifuge (top view). At A, the green dot represents a macromolecule or other particle being sedimented. It would tend to follow the dashed line, heading toward the bottom of the tube, but the fluid resists this motion by exerting a force on the particle as shown at point B.

5–6 Newton's Law of Universal Gravitation

Besides developing the three laws of motion, Sir Isaac Newton also examined the motion of the planets and the Moon. In particular, he wondered about the nature of the force that must act to keep the Moon in its nearly circular orbit around the Earth.

Newton was also thinking about the problem of gravity. Since falling objects accelerate, Newton had concluded that they must have a force exerted on them, a force we call the force of gravity. Whenever an object has a force exerted *on* it, that force is exerted *by* some other object. But what *exerts* the force of gravity? Every object on the surface of the Earth feels the force of gravity, and no matter where the object is, the force is directed toward the center of the Earth (Fig. 5–18). Newton concluded that it must be the Earth itself that exerts the gravitational force on objects at its surface.

According to legend, Newton noticed an apple drop from a tree. He is said to have been struck with a sudden inspiration: If gravity acts at the tops of trees, and even at the tops of mountains, then perhaps it acts all the way to the Moon!

FIGURE 5–18 Anywhere on Earth, whether in Alaska, Peru, or Australia, the force of gravity acts downward toward the Earth's center.