Newton's Mountain

The planets in our solar system appear to have been "orbiting" the Sun while they were forming. Great swirling dust clouds in space began to condense around a newly formed Sun until they finally became the planets. How, then, do artificial satellites begin orbiting Earth?

Soon after Newton formulated his law of universal gravitation, he began thought experiments about artificial satellites. He reasoned that you could put a cannon at the top of an extremely high mountain and shoot a cannon ball horizontally, as shown in Figure 12.6. The cannon ball would certainly fall toward Earth. If the cannon ball travelled far enough horizontally while it fell, however, the curvature of Earth would be such that Earth's surface would "fall away" as fast as the cannon ball fell.

You can determine how far the cannon ball will fall in one second by using the kinematic equation $\Delta d = v_i \Delta t + \frac{1}{2}a\Delta t^2$. If a cannon ball had zero vertical velocity at time zero, in one second it would fall a distance $\Delta d = 0 + \frac{1}{2}\left(-9.81\ \frac{\text{m}}{\text{s}^2}\right)(1\ \text{s})^2 = -4.9\ \text{m}$. From the size and curvature of Earth, Newton knew that Earth's surface would drop by 4.9 m over a horizontal distance of 8 km.

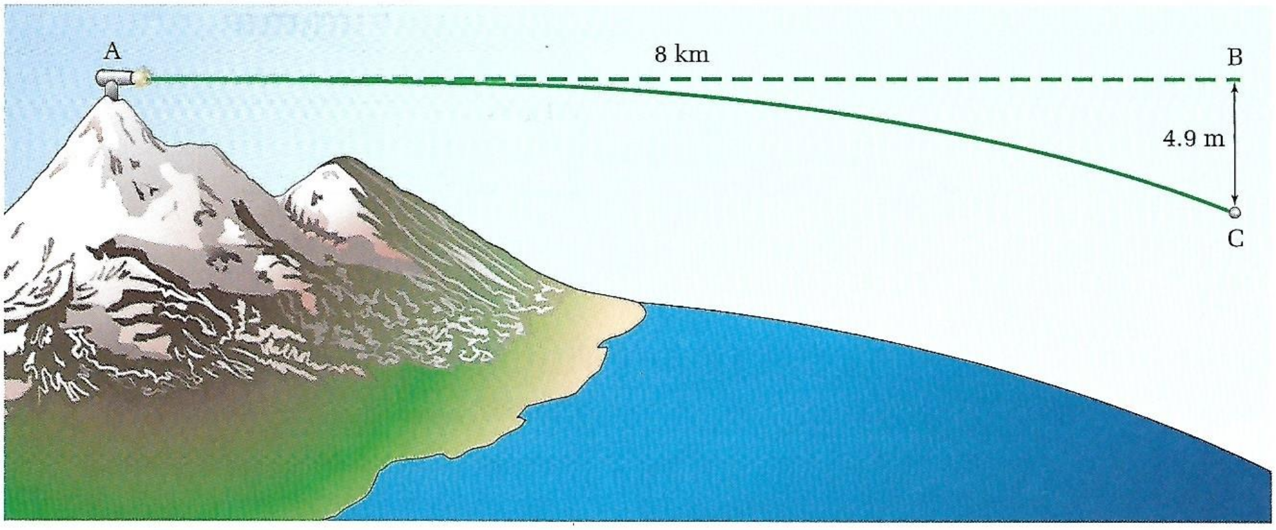

Figure 12.6 The values shown here represent the distance that the cannon ball would have to go in one second in order to go into orbit.

Newton's reasoning was absolutely correct, but he did not account for air friction. Although the air is too thin to breathe easily on top of Mount Everest, Earth's highest mountain, it would still exert a large amount of air friction on an object moving at 8 km/s. If you could take the cannon to 150 km above Earth's surface, the atmosphere would be so thin that air friction would be negligible. Newton understood how to put an artificial satellite into orbit, but he did not have the technology.

Today, launching satellites into orbit is almost routine, but the scientists and engineers must still carefully select an orbit and perform detailed calculations to ensure that the orbit will fulfil the purpose of the satellite. For example, some weather satellites orbit over the Poles at a relatively low altitude in order to collect data in detail. Since a satellite is constantly moving in relation to a ground observer, the satellite receiver has to track the satellite continually so that it can capture the signals that the satellite is sending. In addition, the satellite is on the opposite side of Earth for long periods of time, so several receivers must be located around the globe to collect data at all times.

Communication satellites and some weather satellites travel in a **geostationary orbit** over the equator, which means that they appear to hover over one spot on Earth's surface at all times. Consequently, a receiver can be aimed in the same direction at all times and constantly receive a signal from the satellite. The following problem will help you to find out how these types of orbits are attained.

PHYSICS FILE

Arthur C. Clarke (1917–), scientist and science fiction writer, wrote a technical paper in 1945, setting out the principles of geostationary satellites for communications. Many scientists in the field at the time did not believe that it was possible. Today, geostationary orbits are sometimes called "Clarke orbits." Clarke also co-authored the book and movie *2001: A Space Odyssey*.

MODEL PROBLEM

Geostationary Orbits

At what velocity and altitude must a satellite orbit in order to be geostationary?

Frame the Problem

- A satellite in a *geostationary orbit* must remain over the *same point* on Earth at all times.
- To be geostationary, the satellite must make *one complete orbit* in exactly the same time that Earth rotates on its axis. Therefore, the period must be *24 h*.
- The *period* is related to the *velocity* of the satellite.
- The *velocity* and *altitude* of the satellite are determined by the amount of *centripetal force* that is causing the satellite to remain on a circular path.
- Earth's *gravity* provides the *centripetal force* for satellite motion.
- The values for the mass and radius of Earth are listed in Appendix B, Physical Constants and Data.

Identify the Goal

(a) The velocity, v, of a geostationary satellite

(b) The altitude, h, of a geostationary satellite

continued ▶