this hypothesis revealed the following observations.

1. An object placed between the cathode and the opposite end of the tube cast a shadow on the glass.
2. A paddle wheel placed on rails between the electrodes rolled along the rails from the cathode toward the anode (see Figure 3-5).

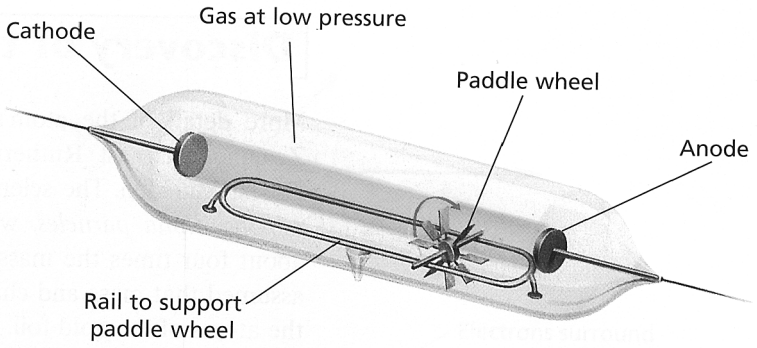

FIGURE 3-5 A paddle wheel placed in the path of the cathode ray moves away from the cathode and toward the anode. The movement of the wheel led scientists to conclude that cathode rays have mass.

These facts supported the existence of a cathode ray. Furthermore, the paddle-wheel experiment showed that a cathode ray had sufficient mass to set the wheel in motion.

Additional experiments provided more information.

3. Cathode rays were deflected by a magnetic field in the same manner as a wire carrying electric current, which was known to have a negative charge.
4. The rays were deflected away from a negatively charged object.

These observations led to the hypothesis that the particles that compose cathode rays are negatively charged. This hypothesis was strongly supported by a series of experiments carried out in 1897 by the English physicist Joseph John Thomson. In one investigation, he was able to measure the ratio of the charge of cathode-ray particles to their mass. He found that this ratio was always the same, regardless of the metal used to make the cathode or the nature of the gas inside the cathode-ray tube. Thomson concluded that all cathode rays are composed of identical negatively charged particles, which were later named electrons.

Charge and Mass of the Electron

Thomson's experiment revealed that the electron has a very large charge for its tiny mass. In 1909, experiments conducted by the American physicist Robert A. Millikan showed that the mass of the electron is in fact about one two-thousandth the mass of the simplest type of hydrogen atom, which is the smallest atom known. More-accurate experiments conducted since then indicate that the electron has a mass of 9.109×10^{-31} kg, or 1/1837 the mass of the simplest type of hydrogen atom.

Millikan's experiments also confirmed that the electron carries a negative electric charge. And because cathode rays have identical properties regardless of the element used to produce them, it was concluded that electrons are present in atoms of all elements. Thus, cathode-ray experiments provided evidence that atoms are divisible and that one of the atom's basic constituents is the negatively charged electron.

Based on what was learned about electrons, two other inferences were made about atomic structure.

1. Because atoms are electrically neutral, they must contain a positive charge to balance the negative electrons.
2. Because electrons have so much less mass than atoms, atoms must contain other particles that account for most of their mass.