Rather it is because he believed that this phenomenon was due to tiny negatively charged particles and made careful measurements on them. Furthermore he argued that these particles were constituents of atoms, and not ions or atoms themselves as many thought, and he developed an electron theory of matter. His view is close to what we accept today, and this is why Thomson is credited with the "discovery." Note, however, that neither he nor anyone else ever actually saw an electron itself. We discuss this briefly, for it illustrates the fact that discovery in science is not always a clear-cut matter. In fact some philosophers of science think the word "discovery" is often not appropriate, such as in this case.

Thomson believed that an electron was not an atom, but rather a constituent, or part, of an atom. Convincing evidence for this came soon with the determination of the charge and the mass of the cathode rays. Thomson's student J. S. Townsend made the first direct (but rough) measurements of $e$ in 1897. But it was the more refined **oil-drop experiment** of Robert A. Millikan (1868–1953) that yielded a precise value for the charge on the electron and showed that charge comes in discrete amounts. In this experiment, tiny droplets of mineral oil carrying an electric charge were allowed to fall under gravity between two parallel plates, Fig. 27–3. The electric field $E$ between the plates was adjusted until the drop was suspended in midair. The downward pull of gravity on a drop of mass $m_{\mathrm{dr}}$ was $m_{\mathrm{dr}}g$, and was just balanced by the upward force due to the electric field. Thus $qE = m_{\mathrm{dr}}g$ so the charge $q$ on a droplet was $q = m_{\mathrm{dr}}\,g/E$. The mass of the droplet was determined by measuring its terminal velocity in the absence of the electric field. Often the droplet was charged negatively, but sometimes it was positive, suggesting that the droplet had acquired or lost electrons (by friction, leaving the atomizer). Millikan's painstaking observations and analysis presented convincing evidence that any charge was an integral multiple of a smallest charge, $e$, that was ascribed to the electron, and that the value of $e$ was $1.6 \times 10^{-19}\,\mathrm{C}$. (Today's value of $e$, as mentioned in Chapter 16, is $e = 1.602 \times 10^{-19}\,\mathrm{C}$.) This value of $e$, combined with the measurement of $e/m$, gives the mass of the electron to be $(1.6 \times 10^{-19}\,\mathrm{C})/(1.76 \times 10^{11}\,\mathrm{C/kg}) = 9.1 \times 10^{-31}\,\mathrm{kg}$. This mass is less than a thousandth the mass of the smallest atom, and thus confirmed the idea that the electron is only a part of an atom. The accepted value today for the mass of the electron is $m_{\mathrm{e}} = 9.11 \times 10^{-31}\,\mathrm{kg}$. The experimental results that any charge seems to be an integral multiple of $e$ means that electric charge is *quantized* (exists only in discrete amounts), as we discussed in Chapter 16.

*Millikan oil-drop experiment*

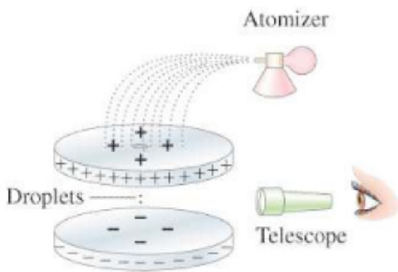


**FIGURE 27–3** Millikan's oil-drop experiment.

## 27–2 Planck's Quantum Hypothesis; Blackbody Radiation

### Blackbody Radiation

One of the observations that was unexplained at the end of the nineteenth century was the spectrum of light emitted by hot objects. We saw in Section 14–8 that all objects emit radiation whose total intensity is proportional to the fourth power of the Kelvin (absolute) temperature $(T^4)$. At normal temperatures $(\approx 300\,\mathrm{K})$, we are not aware of this electromagnetic radiation because of its low intensity. At higher temperatures, there is sufficient infrared radiation that we can feel heat if we are close to the object. At still higher temperatures (on the order of 1000 K), objects actually glow, such as a red-hot electric stove burner or the element in a toaster. At temperatures above 2000 K, objects glow with a yellow or whitish color, such as white-hot iron and the filament of a lightbulb. The light emitted is of a continuous range of wavelengths or frequencies, and the spectrum is a plot of intensity vs. wavelength or frequency. As the temperature increases, the electromagnetic radiation emitted by objects not only increases in total intensity but is strongest at higher and higher frequencies.