March of Discovery

1895

- Wilhelm Roentgen (1845–1923) discovers X rays, for which he would receive the first Nobel Prize in physics, in 1901.

1896

- Antoine Henri Becquerel (1852–1908) observes what he called "uranic rays," the first phenomenon that opens a new field later called radioactivity.
- Wilhelm Wien (1864–1928) publishes his exponential law for black-body radiation, the first quantum law ever written down.
- Pieter Zeeman's (1865–1934) first paper appears on the influence of magnetic fields on spectral lines.

1897

- Determination of *e/m* for cathode rays by J. J. Thomson and others.
- First mention of a particle lighter than hydrogen.

1898

- Ernest Rutherford discovers there are two species of radioactive radiations: α-rays and β-rays.

1899

- Thomson measures the electric charge of free electrons and realizes that atoms are split in ionization processes.

1900

- Paul Villard (1860–1934) discovers γ-rays.
- First determination of a half-life for radioactive decay.
- Max Planck discovers the quantum theory.

1905

- Albert Einstein postulates the light quantum (March).
- Einstein's first paper on special relativity is published (June).

Even before Helmholtz's memorable address, the Irish physicist George Johnstone Stoney (1826–1911) had reported to the 1874 meeting of the British Association for the Advancement of Science an estimate of e, the first of its kind, based on $F = Ne$. Values for F and N were reasonably well known by then. Stoney obtained $e \sim 3\times10^{-11}$ esu, too small by a factor of about 20, yet not all that bad for a first and very early try.[10] In 1891 he baptized the fundamental unit of charge, giving it the name "electron."[11] Thus the term was coined prior to the discovery of the quantum of electricity and matter that now goes by this name.

DECADE OF TRANSITION

IN MARCH 1905 Ernest Rutherford (1871–1937) delivered the Silliman lectures at Yale. He began the first of his talks as follows:

> The last decade has been a very fruitful period in physical science, and discoveries of the most striking interest and importance have followed one another in rapid succession. . . . The march of discovery has been so rapid that it has been difficult even for those directly engaged in the investigations to grasp at once the full significance of the facts that have been brought to light. . . . The rapidity of this advance has seldom, if ever, been equaled in the history of science.[12]

The speed with which one important discovery followed another (see box at left) was indeed breathtaking. It is natural to ask but not easy to answer why so much novelty should be discovered in so short a time span. It is clear, however, that a culmination of advances in instrumentation was crucial. They include:

• *Higher voltages*. Higher voltages were the result of Heinrich Ruhmkoff's (1803–1874) work, beginning in the 1850s, on an improved version of the induction coil. These were the coils that in 1860 served Gustav Kirchhoff (1824–1887) and Robert Bunsen (1811–1899) in their analysis of spark spectra; Heinrich Hertz (1857–1894) in 1886–1888 in his demonstration of electromagnetic waves and his discovery of the photoelectric effect; Wilhelm Roentgen in his discovery of X rays; Guglielmo Marconi (1874–1937) in his transmission of telegraph signals without wires; Pieter Zeeman in his discovery of the Zeeman effect; and Thomson in his determination of e/m for electrons. By the turn of the century, voltages of the order of 100,000 volts could be generated by these coils.