Sir Joseph John Thompson (1856-1940) performed a wide range of experiments which were crucial to our understanding of the electron and the electrical nature of matter. In 1897, he measured the charge to mass ratio of these negatively charged particles. The value he obtained corresponded to the charge / mass ratio for an electron. Thus, there was conclusive evidence that cathode rays were a stream of electrons.

**J.J. Thompson’s e/m\textsubscript{e} Experiment**

He first accelerated electrons which were emitted from a hot cathode in an electric field $E_A$ produced by an accelerating voltage $V_A$ to increase their kinetic energy. The speed of an electron in passing the anode is

$$eV_A = \frac{1}{2}m_e v^2 \quad \Rightarrow \quad v = \sqrt{\frac{2eV_A}{m_e}}$$

where $e$ is the charge of the electron and $m_e$ is the mass of the electron.

The electrons then passed into a region of crossed electric and magnetic fields. A voltage $V$ was placed across a pair of parallel plates with a separation distance $d$. This
produced a uniform electric field \( E = V/d \) which gives an upward deflection of the electron beam (along path X). The electric force \( F_E \) on an electron is

\[
F_E = eE = \frac{eV}{d}
\]

A pair of Helmholtz coil carrying a straight \( I \) produced a uniform magnetic field to deflect the electron beam downward (path Y). The magnetic force \( F_B \) to deflect an electron is

\[
F_B = evB = eB \sqrt{\frac{2eV_A}{m_e}}
\]

Thompson then adjusted the strengths of the electric and magnetic fields so that the electric force and the magnetic force had equal magnitudes so that the electrons travelled straight through the tube without any deflection (path Z). Hence, from measurements of \( V_A, V, B \) and \( d \), the \( e/m_e \) ratio can be estimated:

\[
F_E = F_B \implies eE = evB \quad v = \frac{E}{B}
\]

\[
E = \frac{V}{d} \quad v = \sqrt{\frac{2eV_A}{m_e}} \implies \frac{e}{d} = eB \sqrt{\frac{2eV_A}{m_e}}
\]

\[
\frac{e}{m_e} = \frac{V^2}{2d^2V_A}B
\]

Thompson’s first measurement for \( e/m_e \) was \( 0.77 \times 10^{11} \text{ C.kg}^{-1} \). Even though Thompson’s result was different from the now accepted value of \( 1.759 \times 10^{11} \text{ C.kg}^{-1} \), his measurement was a tremendous achievement. Thompson can be considered the “discoverer” of the electron, although many people contributed to the investigation into the nature of matter. Thompson believed that an electron was not an atom, but a part of an atom.

Another method by Thompson used only a magnetic field to deflect the electron beam. In the absence of the deflecting electric field, the cathode ray beam is bent into a circular path of radius \( R \) due to the magnetic force \( F_B \) on the electrons. The magnetic force produces the centripetal force \( F_C \) hence
magnetic force = centripetal force

\[ F_B = F_C \quad e v B = m \frac{v^2}{R} \quad v = \sqrt{\frac{2eV_A}{m_e}} \]

\[ \frac{e}{m_e} = \frac{2V_A}{R^2 B^2} \]

Alternatively, once the radius of curvature \( R \) has been measured, the electric field \( E \) is adjusted so that the beam has zero deflection and this occurs when

\[ v = \frac{E}{B} = \frac{V}{dB} \quad \Rightarrow \quad \frac{e}{m_e} = \frac{E}{RB^2} = \frac{V}{dRB^2} \]

Measurements of \( V_A, R \) and \( B \) or \( V, d, R \) and \( B \) can then be used to measure the \( e/m_e \) ratio.

Even though Thompson used several different gases in his tube and different metals for his electrodes, he found a consistent value for the \( e/m_e \) ratio. From this observation he argued that there was only one type of electron which must be contained in all atoms.

The basic research into electrical discharges in evacuated tubes led to the invention of the television. The heart of a television set is a large cathode ray tube. Electrons are emitted from a hot cathode and the path of the electron beam can be controlled by varying the applied electric and/or magnetic fields. When the electrons hit the end of the tube a fluorescent phenomenon occurs where the kinetic energy of the electron is transferred into a flash of light producing the television picture. Motorola produced the world’s first cathode ray television in 1947.

This is only one of the many examples where investigations into the fundamental nature of nature has lead to significant changes in technology and society. Without governments investing $$ into basic research, technological and social benefits will be drastically reduced in future.
Web search  YouTube  Thompson’s e/m experiment