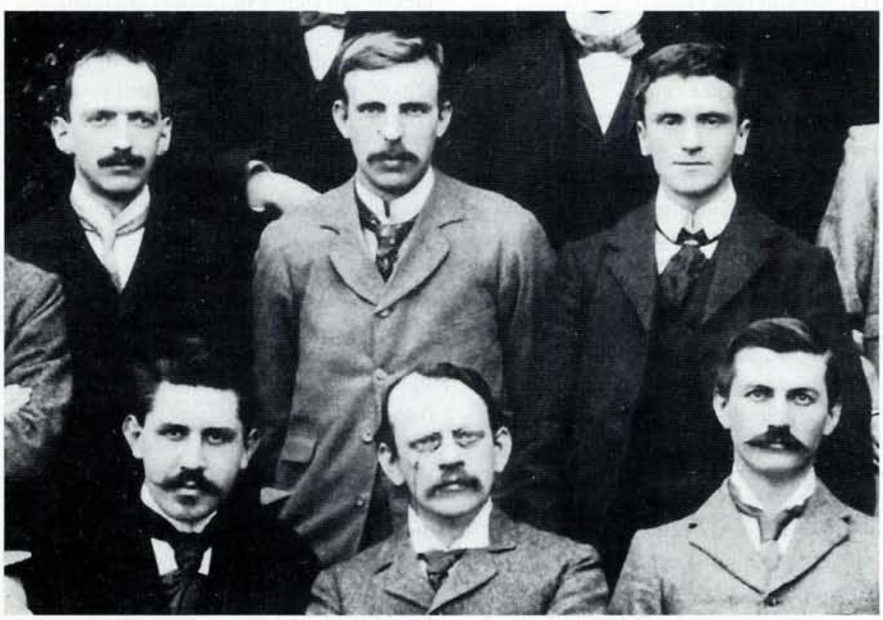
J.J. Thomson and the Discovery of the Electron

By kind courtesy of Sir Brian Pippard FRS, Cavendish Laboratory, Cambridge

The discovery of the electron, 100 years ago, was one among several discoveries in the span of a few years that heralded a new era in physics. It is particularly for the electron that J.J. Thomson is remembered, and the centenary celebrations should cause us to pause and reflect on its significance in our daily lives.

When J.J. (as he was always known, even to his family)was elected to the Cavendish chair of experimental physics he was just 28, and the department was less than 14 years old. J.J.served for 35 years before resigning to become Master of Trinity College and under him the Cavendish grew to international stature. His successor, Lord Rutherford, one of the greatest of modern experimental physicists, raised it to pre-eminence.

J.J.'s youth was only one reason for surprise at his appointment. His gifts were not obviously appropriate to the task. He was too clumsy to handle glassware safely, and he had shown less interest in experiment than in advancing current ideas in mathematical physics: Maxwell's electromagnetic theory and Kelvin's notion of atoms as vortices in the ether. Nevertheless he had made a strong impression on the electors to be preferred above more experienced candidates, and the letters of congratulation he received show how highly he was regarded by many with excellent rival claims. Today it is hard to appreciate the enthusiasm his early papers aroused, we either take his ideas for granted or dismiss the rest as hopelessly outdated and irrelevant. But, of course, in this last flowering of the classical world-picture that Newton had initiated there was no foreboding of how soon it would be swept away, or that its champion J.J. would be one of the instruments of that revolution.



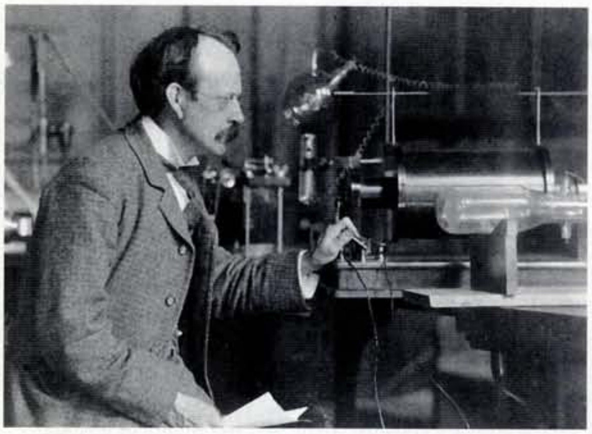
Six men from the 1898 photograph of Prof J.J. Thomson (1856–1949) with the research students. In the fornt row is J.J. with Paul Langevin (1872–1946) on his right and John Zeleny (1872–1951) on his left. Behind, from left to right, are C.T.R. Wilson (1869–1959), E. Rutherford (1871–1937) and W. Craig Herson (1873–1959). Langevin was spending a year in Cambridge and returned to France where he pioneered the introduction of modern theoretical physics. He is particularly remembered for his theories of magnetism and of Brownian motion. Zeleny was Professor of physics at Yale for 25 years. Henderson, a Glasgow graduate, took a D.Sc. there in 1902 before being called to the bar; in 1929 he became Master of the Bench at the Middle Temple.

As a young head of department J.J. soon confirmed the trust that had been put into him. His grasp of the devious ways of equipment grew to be so remarkable that his students, even while they hoped he would not touch their apparatus, were only too glad to hear his suggestions for correcting what was amiss. When he took charge, in 1884, there was no general agreement on the purpose of a physics department. The idea of organised research was accepted in Germany, but there still persisted in Britain a view that universities were for the transmission of established truth, and that the discovery of new truths should be left to rarely gifted individuals. With Rutherford, in 1919, a professor was appointed whose talent was essentially experimental; and yet Maxwell had a strong practical bent and Rayleigh's work on electrical standards was exceptionally good. Both had encouraged practical teaching, and when J.J. came on the scene he found colleagues already developing new methods. He therefore devoted himself to lecturing, which he enjoyed and did well, and to research with the few advanced students who offered themselves.

In his first ten years, up to 1895, the research output of the Cavendish was worthy but hardly spectacular. As well as continuing as a theorist J.J. became seriously involved in experiment, and decided quite early that he would try to understand electrical conduction in gases. The great difficulty was that a gas at low pressure was a non-conductor until the applied voltage was high enough to start a discharge; this was then so vigorous a process that reproducible results were a matter of chance and perseverance. In 1895 J.J. benefitted from the arrival of two gifted students, Townsend from Dublin and Rutherford from New Zealand; at the same time C.T.R. Wilson joined him.

It gives an idea of the spurt in activity to note that in J.J.'s first ten years, he had nine research students who went on to be elected fellows of the Royal Society, while in the next seven years there were thirteen, of whom four won Nobel prizes. Between 1910 and 1914, we find eight students destined for the Royal Society, of whom four won Nobel prizes. These two periods coincide with J.J.'s most influential researches and it is no doubt that the sense of achievement was a powerful attraction.

Another significant event ocurred in 1895 at the very end of the year: the discovery of Xrays by Röntgen. J.J. did not hesit-



J.J. Thomson giving a lecture demonstration of the Braun e/m tube in the 1890s

ate; his assistant Everett began making tubes, and on February 7, 1896, the Royal Society received a short paper describing how Xrays caused gases to conduct electricity. Rutherford and other research students were drawn in and the study of ionisation and recombination in gases became a major activity. The work which in 1897 revealed what is now called the electron may have been stimulated by Xrays but did not make use of them. But we may note how effectively the first use of Xrays clarified J.J.'s ideas, for some of the very odd views he expressed before 1896 vanish in favour of models much more like ours today, and we hear no more, except for the occasional nostalgic reminiscence, of atoms as vortices in the ether.

Turning to the discovery of that subatomic particle that J.J. referred to as a *corpuscle* until, about 1914 he bowed to popular usage and spoke of the *electron*. There was no doubt that this was a particle waiting to be discovered, and three others beside J.J. - Zeeman in Holland, Wiechert and Kaufmann in Germany - within a few months announced evidence for the existence of a negatively charged particle some 1000 times less massive than a hydrogen atom. Zeeman relied on the broadening of spectroscopic lines from an atom in a magnetic field, but he was too prudent to consider that the particle might escape from its atom. Wiechert and Kaufmann, on the other hand, had excellent evidence for light, independent particles but did not follow up their discoveries. They may have experienced the incredulity of those who had never doubted an atom was indivisible. After J.J. had made his announcement at an evening discourse at the Royal Institution, he felt that some in the audience suspected they were being hoaxed, but his authority overcame this first hurdle. The work of the following few years not only firmly established the corpuscle, but showed that it was produced during discharge in every available gas, and from every metal used as electrodes in the discharge tube. It was a constituent of all matter.

As long ago as 1858 Plücker had noted that the cathode in a low-pressure gas discharge tube emitted *cathode rays* which caused the glass of the tube to glow and which cast a shadow of any object in their path. They were rather generally thought in Germany to be wave-like, while in England they were assumed to be particles, probably charged atoms. The particle point of view was not helped by Hertz's observation that, although cathode rays were deflected by a magnet, an electric field had no effect. The suggestion made independently by J.J. and by Fitzgerald, was that the residual gas would be ionised by the passage of charged particles and, being now a conductor, would screen any electric field applied from outside.

J.J. then turned his attention to the electric deflection of cathode rays and found this possible if the gas pressure was made very low. With the assistance of the patient Everett, he determined the deflection of a beam of cathode rays by electric as well as magnetic fields. Comparison of the two deflections then gave the ratio m/e. There was a discrepancy of a factor of two or more, which seems to have caused him no worry - what was significant was that the corpuscle was very much lighter than an atom and was found in all matter.

The discovery of Xrays in 1895, of radioactivity in 1896, and of the electron in 1897 led to a great flowering of physics. J.J. attempted to construct an atomic model incorporating the electron and, although his "currant-bun" model was quite mistaken, the attempt stimulated at least one result of great value. It cannot therefore be dismissed as a total failure, however premature it was without the essential ingredients of Rutherford's nuclear atom and Bohr's quantum theory. Nicholson tried to explain the spectroscopic data in terms of oscillations of the electron distribution. But he replaced the static currant-bun by an extension of Nagaoka's nuclear model with orbiting electrons, and after several failures at classical theories, hit on the idea of quantizing the angular momentum. It was his tentative conjecture, combined with Rutherford's greatly improved nuclear model, that led Bohr to his hydrogen atom.

Once the electron was firmly accepted as a basic unit of atomic structure, J.J. and his students devoted much time to determining its mass and charge as well as possible. The starting point was C.T.R. Wilson's elegant and patient experimental study of cloud formation. The cloud chamber was the ultimate product. A new graduate, O.W. Richardson, presumably at J.J.'s suggestion, studied the emission of electrons from very hot platinum, and provided a quantitative foundation for the thermionics underlying the earliest phase of radio communication, in fact the whole of electronic technology before the invention of the transistor.

J.J. enjoyed a further period of triumphant experiment after about 1907, and especially after 1910 when he was assisted by Aston. From 1919 he was Master of Trinity and in his mid-seventies, when Cockroft and Walton were achieving the artificial transmutations of light elements with their accelerator (1932), J.J. was out of touch with the latest physics. Not that this stopped him from publishing, but his habitual speculative mode now had little relevance to the concerns of the day. He was not the only one of his generation who hoped to reconcile quantum ideas and relativity with the Maxwellian theory he understood so well. There may be little nourishment in his publications after 1914, but we must remember his dogged struggle against impossible odds - the lifelong characteristic of a man who never feared to express half-formed ideas if only they might lead to something better. It was his resilience in failure as much as his great successes, the moral simplicity as well as the intellectual power, that endeared him to a host of colleagues and students, and contributed invaluably to the creation of a justly famous research school.

Further Reference

J.J. published his reminiscences when he was 80: *Recollections and Reflections* (London, Bell: 1936). Lord Rayleigh wrote *The Life of Sir J.J. Thomson OM* (Cambridge University Press: 1942).