Positively Negative

THE IDENTITY OF THE ELECTRON

by Greg Grant

It began with a very basic problem; the nature of electricity. In 1733, the French physicist Charles-François du Fay discovered that two pieces of cork, electrically charged by the same means, repelled one another. If, however, one piece was charged by an electrified glass rod, it attracted a similar piece charged by a resin rod. From these experiments, du Fay concluded there were two distinct types of electrical fluid, one which he termed resinous electricity and the other vitreous electricity, from the Latin word for glass.

Fourteen years later, that great American all-rounder, Benjamin Franklin, rejected this hypothesis. As he saw it, there was simply one fluid or electrical substance which could exist in one or two conditions, namely an excess or a deficiency. Excess repelled excess and deficiency rejected deficiency because they had nothing concrete to offer one another. Excess, however, would attract deficiency and so the electrical fluid or substance flowed from excess to deficiency.

Not surprisingly, Franklin proposed that the excess be termed Positive Electricity, and the deficiency Negative Electricity, but did not determine which was resinous and which was vitreous.

Over the next century, or thereabouts, some of electricity's secrets were uncovered by minds of the quality of Volta and Oersted; Faraday and ampere; Ohm and Henry. Yet the phenomenon's fundamental nature remained elusive.

In 1846, however, matters began to move forward when the German Physicist, Wilhelm Weber and his collaborator, Karl Freidrich Gaus, applied the units based on mass, time and length that they had developed for magnetism, to electricity.

Electricity's nature, though, was still tantalisingly distant and so science began to consider the vacuum, and for a very simple reason. If an electric current could be forced through one, it could be observed in isolation, devoid of outside factors or influence.

The vacuum's original method of creation, already 200 years old, was still the easiest and most effective. What Evangelista Torricelli had done in 1643 was fill a 1·82m long glass tube with mercury, cork it and then upend it in a bath of mercury. When he removed the cork, the mercury dropped until there was a column of about 76cm still in the tube. Above that, of course, was a vacuum, in fact, the first ever artificially created one.Shortly, other physicists considered the possibility of producing a more effective scientific vacuum.

Two years after Torricelli, Otto von Guericke invented the first practical air pump and twelve years later, Robert Hook designed a faster acting, more effective pump, much used by the chemist Robert Boyle. Yet neither pump gave as good a vacuum as Torricelli's simple technique.

Clearly, what was needed was a pump capable of delivering a Torricellian vacuum. In 1855, the German inventor, Heinrich Geissler, taking advantage of Torricelli's discovery, produced just such a pump. It moved a column of mercury up and down, making the vacuum above the column suck air out of a container. Using this device, Geissler succeeded in producing the first decent vacuum tubes, an example of which is shown in Figure 1.

Three years later, the university of Bonn's Professor of Physics, Julius Plucker and his research assistant, Johann Hittorf, showed, using a Geisslar Tube, that electrical rays bend under the influence of a magnet. This suggested that such rays were, in some way, connected with electric charge.

This discovery, it may be said, began the scientific investigation not only of the nature of electricity but of the atom also.

By 1869, Hittorf, now a university lecturer, discovered that an object placed in front of a point-source cathode cast a shadow on the glow discharge. He concluded that whatever was leaving the cathode was doing so in a straight line.

Two years later, the British electrical engineer, C. F. Varley, developer of the Varley Loop Test for cable fault location, demonstrated that the rays in a Geissler tube could also be deflected by an electric field. He put forward the view that such rays must be metal particles 'pulled' from the negative pole by electricity.

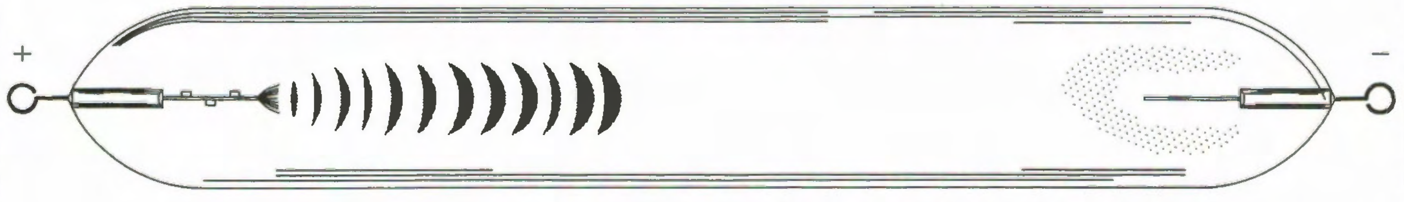

Figure 1. An example of a Geissler Tube from the early 1890s.

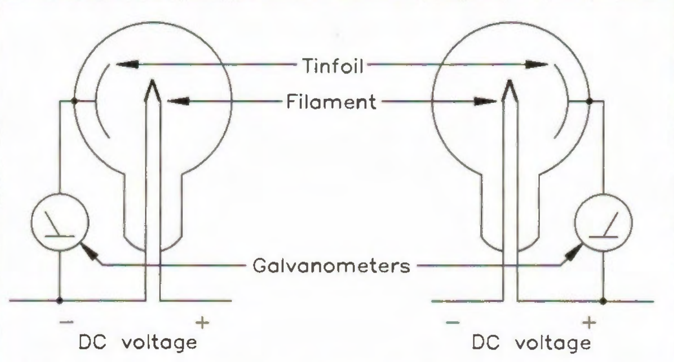

Figure 2. Edison's simple arrangement that revealed the nature of electrons. Subsequently known as the 'Edison Effect.'

In 1875, Sir William Crookes developed what came to be known as the Crookes Tube, an improved version of Geissler's original, with which he began his extensive research into electrical rays.

In the following year, Eugen Goldstein, studying at the University of Breslau, demonstrated that electrical rays were emitted from the whole cathode, not a particular point or points on it. Such rays could also, he found, cast sharp shadows.

Goldstein was the first physicist to use the expression Cathode Ray, doing so because he believed the fluorescence in the tube to be a radiation stream flowing from the cathode.

The word comes from the Greek 'Kata', meaning down and 'Hodos' meaning route, it having been evolved earlier by Faraday and Whewell to describe one of the components of a secondary cell. Goldstein's work led to the manufacture of concave cathodes so as to produce focused rays.

In 1878, Crookes reported on his research into cathode rays specifically and the vacuum discharges generally. He suggested that the rays "were due to the few gas molecules still remaining in the tube becoming electrified and then being repelled from the cathode."

In a lecture to the British Association for the Advancement of Science in the following year, Crookes spoke of cathode rays "casting shadows.. warming obstacles and (being) deflected by a magnet."

Crookes had also shown that the magnet made the rays curve in such a way as to suggest they were negatively charged. In short, Crookes concluded, such 'rays' were a stream of negative particles. This would prove to be prescient to say the least.

His report and subsequent lectures brought him a great deal of public attention, far more indeed than that accorded to Johann Hittorf for his no-less-extensive and equally fruitful researches.

By 1881, the great Herman von Helmholtz had entered the debate, with the opinion that electricity was composed of discrete particles which behaved like atoms of electricity. In the following year, science came tantalisingly close to a fundamental breakthrough in understanding, not to mention electrical technology.

The American inventor, Thomas Edison, was investigating the failure of his version of the incandescent lamp, whose filaments kept burning out and blackening the inside of the bulbs. In the course of this work, Edison decided to try a little experiment.

He covered the inside of a new bulb with tinfoil and connected it to the negative terminal of the filament battery via a galvanometer. When he switched on, nothing happened. On his connecting the tinfoil to the positive terminal however, the galvanometer registered a small current, as shown in Figure 2.

Edison, of course, kept voluminous notes, and so the above investigation was recorded, the result becoming known as the Edison Effect, and two years later, he applied for a patent on an electrical indicator based on his observations. This was surely the classic missed opportunity by the greatest inventor of the day or indeed, any day. It also illustrates the very considerable part the quest for decent lighting played in the development of what would later come to be called 'electronics'.

That a good vacuum was still difficult to achieve however, was demonstrated in 1883, when Heinrich Hertz, using a tube which was obviously defective, found that cathode rays were not deflected by a charged metal plate. He concluded, incorrectly, that the rays could not be charged particles. Seven years later, Arthur Schuster calculated the rate of charge to mass of the particles making up cathode rays by measuring their magnetic deflection.

In 1891, the Irish physicist, George Johnstone Stoney, gave the name 'Electron' to what many of his scientific colleagues kept hoping would prove to be the fundamental unit of electricity.

Shortly after Stoney's intervention, Hertz appeared to get it wrong again when he showed that cathode rays could penetrate thin metal foil, and concluded that this supported the wave hypothesis as an explanation of the phenomenon. In fact, he was not so much wrong as ahead of his time. Another 30 years or more would pass before science would accept the wave-particle duality.

By 1894, the British physicist, J. J. Thomson, had established that the velocity of cathode rays was considerably lower than the speed of light, and in Germany, the physicist Philipp Lenard was expanding the possibilities of the Geissler Tube.

He manufactured discharge tubes with thin aluminium windows, which enabled the cathode rays to pass out of the tube and "be detected by the light they produced on a screen of phosphorescent material."

Lenard also demonstrated that cathode ray absorption "was roughly proportional to density, and that the rays became more penetrating with increased voltage."

In the following year, the French physical chemist, Jean-Baptiste Perrin, working towards his doctorate, decided to investigate cathode rays. His method was to direct a beam of rays across the diameter of an evacuated flask, as illustrated in Figure 3. He then attached a small cylindrical metal cup on the far wall of the flask, offset to one side of the beam's axis. Using a magnet, '.. Perrin diverted the beam into the cylinder. (It) acquired a substantial negative charge.'

Both the charge and direction of the magnetic field proved what Crookes had already surmised, cathode rays were indeed negative particles, not wave radiation.

Perrin also worked out the charge-to-mass ratio of these particles by the simple expedient of measuring the negative charge required to stop them illuminating a fluorescent screen. The identity of electricity's fundamental unit had been determined, at last.

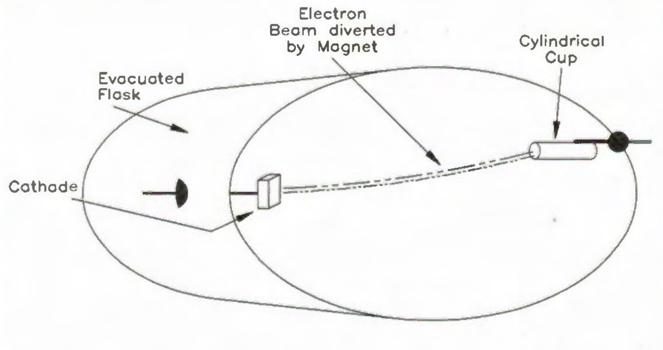

Figure 3. Jean-Baptiste Perrin's experimental apparatus for determining the nature of cathode rays.

Further Reading

The Cambridge Illustrated History of the World's Science. CUP/Newnes Books, Cambridge, 1983.

Electronic Inventions 1745-1976. GWA Dummer. Pergamon Press, Oxford, 1977.

Serendipidy: Accidental Discoveries in Science. John Wiley & Sons Inc., New York. 1989.

Pioneers of Science. Robert L. Weber. Adam Hilger, Bristol. 1980.

Ibid (4).Captions.