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MILLIKAN'S OIL DROPS, ELECTRON CHARGE, AND COOKED DATA

Joseph John Thomson (1856-1940) is often credited by the media with discovering the electron, but evidence that cathode rays consist of negatively charged particles was first demonstrated by William Crookes (1832-1919), and Jean-Baptiste Perrin (1870-1942), and others, who showed the rays could be deflected by a magnetic field and charge a body upon which they fell. The problem was that no one could deflect the rays with an electric field, and if the rays consisted of negatively charged particles, that should certainly occur. Thomson's contribution, which he made in 1897 and which was indeed essential, was to demonstrate that under the proper experimental conditions of lower gas pressure, cathode rays can also be deflected by an applied electric field. Photographs of Thomson usually show him in his middle age, but he was all of 28 when he succeeded Lord Rayleigh as professor and head of the Cambridge Cavendish Laboratory, and 31 years old when he confirmed the demonstration of the existence of the electron in 1897 and calculated its approximate mass.

What was known exactly was the ratio of charge to mass of the electron, and it was thus important to determine the magnitude of the charge carried by the "corpuscles" (only later called "electrons"). John S. Townsend (1868-1957), one of Thomson's research students, was assigned the task of determining the charge. Townsend used clouds of ionized water vapor: By observing the rate of fall of the cloud and applying *Stokes' law for the free fall of spheres through a viscous medium, Townsend was able to determine the size of the droplets; from a measurement of the total amount of water in the cloud, he then calculated the number of droplets contained in the cloud; having also measured the total charge on the cloud, he was able to calculate the charge on a single ion as 3 x 10^(-10) electrostatic units (esu). A later measurement by Thomson produced the value 6.5 x 10^(-10) esu. (The present established value is 4.803 x 10^(-10) esu or 1.602 x 10^(-19) coulombs.)

The inexactness of the water-cloud method was due primarily to evaporation of the water droplets during the experiment (which changed their volumes), and a more exact measurement of electron charge was made by Robert A. Millikan (1868-1953) and his assistants in 1910-1912 using oil droplets, for which Millikan received the Nobel Prize in Physics in 1923. Millikan reported 4.774 x 10^(-10) esu as the value of the electron charge. One problem with the analysis of the oil-drop experimental data, a problem well-recognized by Millikan, is that Stokes' law requires a continuous medium, and the oil droplets in the experiment are small enough so that an assumption of a continuous medium is not completely justified. Millikan arbitrarily added a correction term to the Stokes' equation and devoted great effort to estimating the magnitude of this correction.

Millikan obtained his PhD at Columbia University in 1895, and was on the faculty of the University of Chicago from 1896 to 1921, and at the California Institute of Technology from 1921 to 1945. At Caltech, Millikan had much responsibility for university policy, and many consider him the "patron saint" of the California Institute of Technology.

Recently, however, Millikan has been sharply criticized for effectively swindling a graduate student, Harvey Fletcher, out of credit for the oil-drop experiments, and even for "cooking" the data used in his [Millikan's] classic paper reporting the experiments.

The following points are made by David Goodstein (American Scientist 2001 89:54):

1) At about 1910, Millikan assigned a new graduate student, Harvey Fletcher (?-1982), the task of devising a way to use mercury or glycerin or oil, instead of water, in droplet experiments to establish the charge of the electron. Fletcher immediately set up a crude apparatus involving minute droplets of watch oil, the droplets created by an ordinary perfume atomizer. Through the eyepiece, Brownian motion caused

by the impacts of unseen air molecules on the oil droplets could be observed and measured. Within a few years, Fletcher and Millikan, working with this basic apparatus, had an accurate value of the electron charge and a determination of the product (N)(e), where (N) is Avogadro's number and (e) is the electron charge, the product derived from the observations of Brownian motion. Thus, two separate research papers from this work were possible. The academic rules of that time allowed Fletcher to use a published paper as his PhD thesis, but only if he were the sole author. Evidently, Millikan, who was then 40 years old and had not yet made a mark in physics, approached Fletcher with a "deal": Fletcher would be sole author on the Brownian motion paper (which was less important), and Millikan would be sole author on the electron-charge paper. Goodstein states: "No doubt Millikan understood that the measurement of [electron charge] would establish his reputation, and he wanted full credit. Fletcher understood this too, and he was somewhat disappointed, but Millikan had been his protector and champion throughout his graduate career, so he had little choice but to accept." This manipulation by Millikan first became widely known only in the early 1980s.

2) Concerning mishandling of data by Millikan, the view is widespread that Millikan "cooked" the data (i.e., retained only those results that fit his conclusions and discarded other results) for his important 1913 paper amplifying the electron-charge measurements with the oil-drop technique. It was essentially this paper that led directly to the Nobel Prize. Goodstein states: "He published the results of measurements on just 58 drops, whereas the notebooks reveal that he studied some 175 drops... And to make matters worse, he lied about it. Millikan's 1913 paper contains the following explicit assertion: 'It is to be remarked, too, that this is not a selected group of drops, but represents all the drops experimented upon during 60 consecutive days. during which time the apparatus was taken down several times and set up anew."

3) But having made a detailed examination of Millikan's notebooks and the published 1913 paper, Goodstein concludes that, albeit not explicitly, Millikan implicitly indicates in the 1913 paper that measurements on only 58 drops were presented because measurements on 117 drops were considered incomplete, the drops too small (too subject to Brownian motion) or too large (falling too rapidly for velocity to be measured), etc. Goodstein states: "What scientist familiar with the vagaries of cutting-edge experimental work would fault Millikan for picking out what he considered to be his most dependable measurements in order to arrive at the most accurate possible result?"

[Editor's Note: Admitting the "vagaries of cutting-edge experimental work", and admitting that in this case the final numerical results would probably /not/ have changed had all the measurements been included, we still strongly disagree with the assessment by Goodstein. We believe that what Millikan should have done was publish /all/ his data, then explicitly discuss in his paper the reasons for discarding data on 117 out of 175 drops. What Millikan did instead was essentially conceal his selection of only 58 drops by using ambiguous language, and thus he truly "cooked" the data for publication.]

4) Goodstein concludes: "Like anyone, [Millikan] had his strengths and his flaws. He wasn't generous enough to put his student's interests ahead of his own at a critical point in his career. In describing the results of his oil-drop experiment, he let himself get carried away a bit in demonstrating the correctness of his empirical correction to Stokes' law... But Robert Andrews Millikan was not a villain. And he certainly did not commit scientific fraud in his seminal work on the charge of the electron."

Notes:

Stokes' law: This law, discovered by George Stokes (1819-1903), predicts the frictional force (F) on a spherical ball moving through a viscous medium, with F given by 6?rnv, where (r) is the radius of the ball, (n) is the viscosity of the medium, and (v) is the velocity of the ball. For a falling ball, the force (F) equals the gravitational force on the sphere, less any upthrust.