feature article

Remembering the oil-drop experiment

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In their memoirs, Robert Millikan and Harvey Fletcher describe what happened during the months leading up to their now-famous measurements on charged droplets. But intriguing differences in the accounts make it unclear just who made the key contributions.

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In 1910 Robert Millikan of the University of Chicago announced that he and Harvey Fletcher had developed a successful means of isolating and measuring the charge of an electron. This exciting breakthrough, which became known as the oil-drop experiment, was a major contribution to physics. Millikan received worldwide recognition for the experiment, including the Nobel Prize in Physics in 1923. He published a great deal regarding the implications of the measurements and ultimately became one of the most influential physicists of the 20th century.

Fletcher enjoyed a distinguished career in the field of communication acoustics, but his contribution to the oil-drop experiment was largely forgotten. His version of the story remained untold until 1982, when after his death PHYSICS TODAY published an excerpt from his unpublished 1967 autobiography[1] detailing his involvement with Millikan on the famous experiment (see PHYSICS TODAY, June 1982, page 43). While it offered much new information about the oil-drop experiment, Fletcher's memoir also seemed to contradict certain aspects of Millikan's autobiography, making reconstruction of several key details regarding their work very difficult.

Physicists with ambition

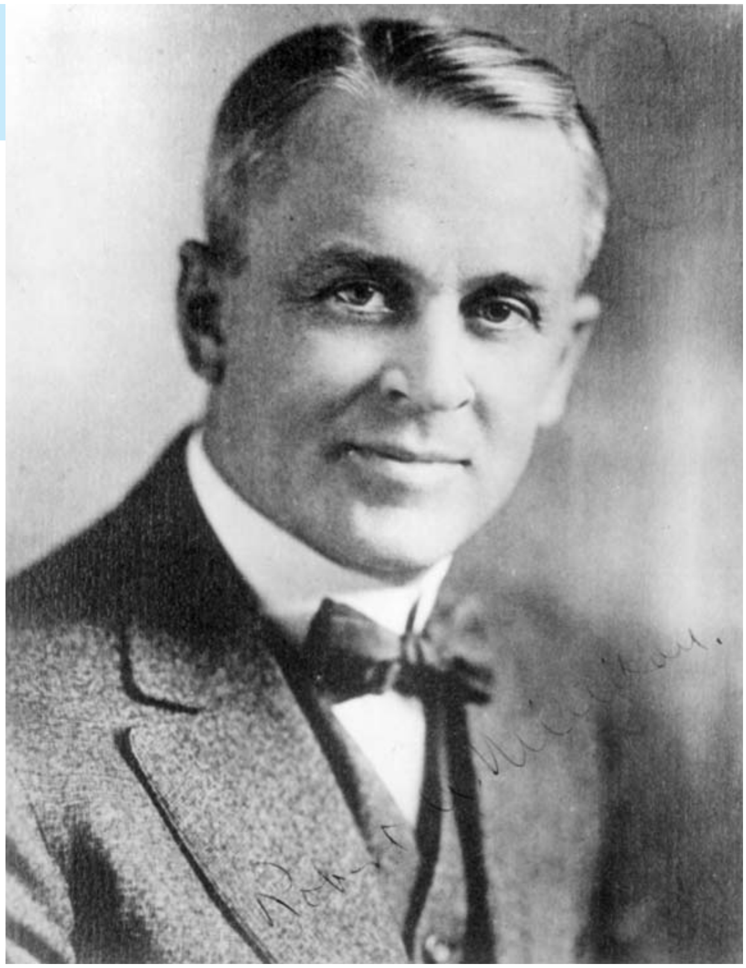
Millikan first arrived at the University of Chicago in 1896, a time when the foundations of physics were being radically altered.[2] Little more than a decade earlier, researchers had thought of atoms as indivisible, but recent discoveries were overturning that assumption. Wilhelm Röntgen had discovered x rays, Henri Becquerel had discovered radioactivity, and J. J. Thomson was on the verge of discovering the electron through his measurements of the constant charge-to-mass ratio of cathode rays. Millikan wished to be at the frontier of this scientific revolution, and he arrived at Chicago eager to make his mark as an experimentalist. His goal was difficult since his university contract required that he spend six hours a day teaching, writing textbooks, preparing lectures, and organizing a systematic program of study. By working 12-hour days, Millikan managed to do research as well, but not to the extent he wished. As the years passed, he became frustrated that he "had not yet published results of outstanding importance, and certainly had not attained a position of much distinction as a research physicist."[3] Although he was not in danger of losing his position, he longed for a breakthrough that would earn him a place of honor in his field.

Millikan eventually began to focus on isolating and measuring the magnitude of the discrete charge of the electron, a problem that he remembered "everyone was interested in" solving.[3] Indeed, the problem was radically new and was of central importance to physicists because of its relevance to a potentially wide range of scientific applications.[4]

By 1908 Millikan was doing his research with a graduate student named Louis Begeman. The two reconstructed an experiment performed five years earlier by a British scientist named Harold A. Wilson. The experiment used x rays to produce successive ionized cloud formations between two horizontal metal plates, with the goal of measuring the rate of fall of the charged droplets in the cloud. Disappointed with the results, Millikan built a 4000-volt battery to charge the plates to a high enough voltage to suspend single charged droplets of water between them. After performing the experiment, Millikan and Begeman published results that "were somewhat more consistent than those reported by Wilson,"[5] but the publication did not bring Millikan the credit or fame that he sought. Millikan and Begeman's calculations lacked precision because the water droplets evaporated too quickly.

Harvey Fletcher arrived at the University of Chicago the same year. A recent graduate of Brigham Young University, Fletcher was ambitious, newly married, and eager to pursue a PhD in physics. He had excelled at BYU and had joined the faculty immediately after graduation. But he had never published a scientific article, and his professional reputation did not extend beyond the mountainous boundaries of Utah Valley, where he had lived his entire life.

Soon after arriving in Chicago, Fletcher was shocked to learn that his application to the graduate school had been denied. The admissions committee, apparently unimpressed with Fletcher's credentials, ruled that he must complete four more years of undergraduate work before being admitted to the PhD program. Devastated, Fletcher turned to Millikan for advice. The two had met for the first time only a few days before, but Fletcher had been impressed by Millikan's friendliness during their first acquaintance, and he had taught from one of Millikan's physics texts at BYU. Fortunately for Fletcher, Millikan soundly advised him to enroll in the university as a special student and complete the coursework out-



Robert Millikan (1868–1953), circa 1923, the year he won the Nobel Prize in Physics. (Courtesy of AIP Emilio Segrè Visual Archives.)

lined for first-year graduate students. He reasoned that if Fletcher could prove that his coursework at BYU had prepared him to succeed, the admissions committee might reconsider its decision. Fletcher followed that plan and, after excelling in the classes, began the PhD program in the fall of 1909.[1] He remained in at least minimal contact with Millikan during his trial year, and Millikan helped him secure a paid assistantship with the physics department for the following year.[6]

Conflicting memoirs

Millikan and Begeman were still struggling with their water-droplet experiments in the fall of 1909, Fletcher's first semester as an official degree-seeking candidate. Four decades later, in his 1950 autobiography, Millikan wrote that the idea to substitute oil for water in the experiments came to him in September 1909, as he was returning from a scientific conference in Canada:

> Riding back to Chicago from this meeting I looked out the window of the day coach at the Manitoba plains and suddenly said to myself, "What a fool I have been to try in this crude way to eliminate the evaporation of water droplets when mankind has spent the last three hundred years in improving clock oils for the very purpose of obtaining a lubricant that will scarcely evaporate at all."[3]

Fletcher remembered the origin of the oil idea differently. He wrote that he approached Millikan in December 1909 to discuss a topic for his doctoral thesis. At a prearranged time, he met with Millikan and Begeman, and the three men discussed the water-droplet experiments and postulated testing various substances that would not evaporate so quickly. Fletcher remembered leaving the meeting "with the impression that I had suggested oil" and that Millikan told him after the discussion, "There is your thesis; go try one of these substances which will not evaporate."[1] Aware of Millikan's conflicting autobiographical account, Fletcher was careful in his narrative not to accuse Millikan of lying. In describing the experience, Fletcher qualified his claim: "In a discussion of that kind, it is rather difficult to be sure who suggested what."[1]

Fletcher's memoir also seems to contradict Millikan's statements regarding the implementation of the correct equipment to measure the oil droplets. Millikan recorded that after his September revelation he "went at once to the shop and had the mechanic build me an air condenser" so that he could begin to use oil in his experiments.[3] Fletcher, however, wrote that the two of them together spoke with the mechanic and "outlined a new design for our apparatus,"[1] only after Fletcher had first constructed a working model. According to that account, Fletcher was eager to begin tests after meeting with Millikan and Begeman, and he immediately began building a crude apparatus similar to the one they had been using. With clamps, Fletcher suspended two circular brass plates approximately two centimeters apart. He placed an arc light behind a piece of cardboard and focused the light beam through a hole in the cardboard so that no part of the beam would touch the plates between which the droplets were to be sprayed. Fletcher then connected a 1000-volt battery to the brass plates to charge them and pointed a telescope toward the area between the plates.[1]

When he was ready to test his apparatus, Fletcher turned on the light and sprayed a mist of watch oil through a small hole in the center of the top brass plate. He later described the results of this first trial:

> As I looked through the telescope I could see the tiny stream of oil droplets coming through the hole. . . . As soon as I turned on the switch some of them went slowly up and some went faster down. I was about to scream as I knew then some were charged negatively and others positively. By switching the field off and on with the right timing one could keep a selected droplet in the field of view for a long time. I went immediately to find Professor Millikan. . . . He came down to the laboratory and looked through the telescope and saw the same beautiful sight . . . that I had already seen and have described above. He was very much excited . . . [and] was sure he could get an accurate value of *e* [the charge of an electron] by this method. He stopped working with Begeman and started to work with me. We were together nearly every afternoon for the next two years.[1]

Though this sequence of events disagrees with several details from Millikan's autobiography, Fletcher's account is plausible and explains several issues left unclear by Millikan. For example, Millikan had been working with Begeman for

Harvey Fletcher (1884–1981), with his wife, Lorena Chipman, shortly after their wedding in September 1908. (Courtesy of University of Utah Library Special Collections.)

at least a year when he suddenly stopped and began working with Fletcher; in all the years following the experiment, Millikan never mentioned Begeman in connection with the oil-drop phase of the research. If Fletcher had been influential in developing this method, it makes sense that Millikan would have wanted to work exclusively with him. Indeed, beginning in December 1909, the two worked together on the oil-drop experiment for more than a year and a half.[7] Also, Millikan wrote in his autobiography that the results of the experiment "came out of the oil-drop technique, as initiated by Harvey Fletcher and myself."[3] This statement seems to contradict Millikan's own assertions in the same book that he alone thought of using oil and designed the equipment necessary to measure the fall of the oil droplets.

Despite the discrepancies in the scientists' respective accounts, it is probably unfair to accuse either man of embellishing his contribution to the experiment. Many decades elapsed between their work together and the time they wrote their memoirs. Fletcher supposed that when Millikan "wrote his memoirs shortly before he died he had probably forgotten some of these early experiences."[1] Perhaps the same thing could be said of both men.

Sharing credit

On 25 May 1910, the *Chicago Tribune* reported that Millikan had announced the preliminary results of the oil-drop experiment at the University of Chicago the day before. In his speech Millikan acknowledged having performed the experiments with Fletcher, but he was also quoted as saying that their results were achieved through a "method of my own." Millikan was clearly claiming the bulk of the responsibility. This was not necessarily unfair—Millikan had been working on the experiment for more than a year before Fletcher arrived, and the method of using a high-voltage charge to isolate individual droplets was largely his brainchild, even if Fletcher had suggested using oil in the experiment and had helped design the equipment used.

As time passed and the results of the experiment were more widely reported, the pattern established in that first newspaper article held true. Millikan received most of the credit but continued to acknowledge Fletcher's role in the work. In September 1910, for example, in a publication outlining the preliminary results of the work, Millikan mentioned Fletcher by name five times and at one point stated, "Mr. Harvey Fletcher and myself . . . have worked together on these experiments since December 1909."[7] Similar statements appeared in subsequent books that described the oil-drop method. In his 1917 book *The Electron* Millikan referred to Fletcher several times and described the experiment as a joint one.[8] Millikan's autobiography mentions Fletcher only once in connection with the experiment, but in a way that closely connects him to its initiation. In each case Millikan emerged as the driving force behind the experiment.

Fletcher did not seem to mind being remembered as a secondary contributor. Not once during Millikan's lifetime is Fletcher known to have written or said anything to indicate dissatisfaction with the amount of recognition he received. To the contrary, he seemed pleased that his name was associated with the project. Soon after *The Electron* was published, Fletcher wrote to his friend and former mentor, "I wish to compliment you on the very interesting and comprehensive way in which you have presented the subject, and to thank you for the fair acknowledgments that you have given me for that part of the work to which I contributed."[9] Fletcher also later remembered feeling thrilled that his "name ran right along with Professor Millikan's in the newspaper"[1] when the oil-drop announcement was made. When Millikan received the Nobel Prize, Fletcher sent him a congratulatory note in which he asserted that the "Nobel Prize was well placed."[10]

It seems that Fletcher was genuinely pleased for Millikan. One might ask, then, what motivated Fletcher to write his conflicting memories of the experience in 1967, after so many years of seeming contentment. The answer may be closely tied to Millikan's 1950 autobiography. In that account Millikan claimed that he alone thought of using oil instead of water in the experiment and describes how he designed the apparatus necessary to properly measure the charged droplets.

Fletcher had been willing to cede Millikan the bulk of the credit for the experiment as a whole, but it bothered him when he felt that his former mentor was claiming sole responsibility for developments that he remembered initiating. Still, Fletcher was unwilling to go public with his narrative—which he wrote for his children—and he ensured that the account remained unpublished during his lifetime.

The most stunning element of Fletcher's account is his claim that after the initial results were ready for publication, Millikan used his leverage as thesis adviser to assert sole authorship for the most notable of the papers, later entitled "The Isolation of an Ion, A Precision Measurement of Its Charge, and the Correction of Stokes's Law."[7] They had written the paper together, Fletcher remembered, and he assumed it would be a joint publication. Before it was sent to press, however, Millikan approached him and pointed out a rule in place at the University of Chicago at the time: A graduate student had to be the sole author of any published paper that would be used as a doctoral thesis. Because the two were also working on four other papers at the time, Millikan offered to allow Fletcher to be the sole author of one of those

This graffiti-covered steam shovel, photographed on the Caltech campus in 1937, suggests that Millikan, although famous, did have his detractors, even at his own school. (Courtesy of the Archives, California Institute of Technology.)

other papers if he (Millikan) could be the sole author of the first paper. Fletcher possibly could have resisted Millikan's suggestion, but he ultimately agreed to the arrangement. He wrote in his autobiography that he did not have bad feelings toward Millikan, and he expressed gratitude that Millikan had helped him get into the graduate program in the first place, but he was clearly disappointed.[1]

The paper mentions Fletcher by name many times and almost exclusively uses the plural pronoun "we" to describe the experimental process. But such acknowledgments are common in scientific publications. If Fletcher's claim is true, it suggests that Millikan was quite protective of his own rise to stardom.[2] Certainly that first paper was the breakthrough Millikan had been longing for since his arrival at the University of Chicago, and in many ways it became a stepping stone to worldwide fame. The experiment was and always would be primarily Millikan's, however. Although clearly instrumental in developing the successful method to isolate and measure ions, Fletcher worked on the experiments directly with Millikan for less than two years; Millikan spent the better part of a decade continually refining the experimental process and achieving more precise results.[11]

Fletcher's autobiography notes that some of his fellow students spoke poorly of Millikan and that "rumors persisted at the [University of Chicago's] Ryerson Physical Laboratories for many years" that he had mistreated Fletcher. Because he felt that some of those rumors were "magnified beyond the real truth,"[1] Fletcher recorded his version of the events in order to set the record straight. In 1921 Millikan left the University of Chicago to help develop the recently founded California Institute of Technology. He played a large part in establishing the institute as a world-class school, and during his tenure it was sometimes referred to as "Millikan's School." At least one person there regarded Millikan's reputation as overstated and painted graffiti on campus property: "Jesus saves but Millikan gets credit."[12]

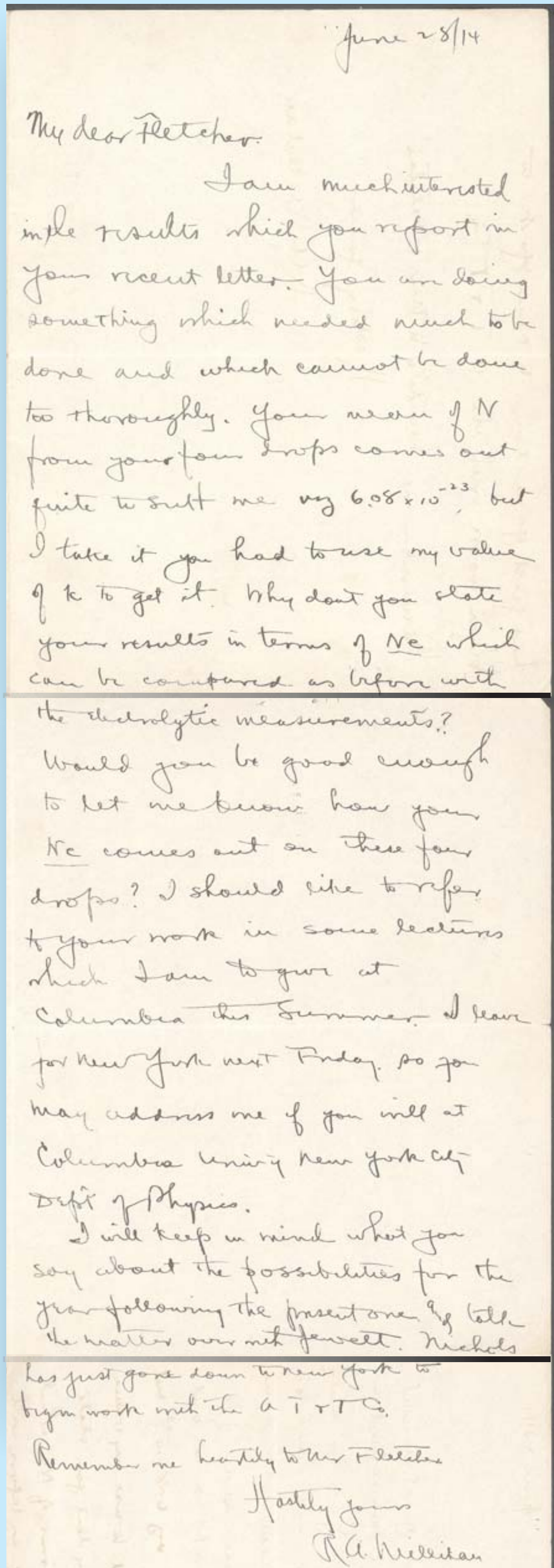
In the spring of 1911, Fletcher became the first University of Chicago student to graduate summa cum laude with a PhD in physics. He wrote to a friend in Utah that the university offered him a position on the faculty—which meant that he could have continued to work with Millikan. Fletcher declined the offer, however, because he felt an obligation to return to BYU. Perhaps part of the decision involved Fletcher's realization that Millikan had already established a claim to the lion's share of the credit and that staying would not change that fact.

The two men parted on good terms and even continued to work on various aspects of the experiment. In January 1912 Millikan wrote to Fletcher about an article that called into question some of the equations they had been using to calculate e. By then Fletcher had assembled a working apparatus at BYU and Millikan vaguely referred to the project as a joint one: "This will not [affect] the value of e very much, but it does influence it some. I think there are a couple of years of work to be done on that before we get it in such shape as we want to see it in."[13]

They were no longer research partners, but they were both working on common issues. In Provo, Utah, Fletcher was focused on the implication of Brownian motion in the oil-drop process. His research was fruitful, and he published two additional papers as a result of continued experiments. Millikan was pleased that Fletcher had continued studying the problem and wrote him in 1914, "This matter is becoming of more and more importance every day and I am exceedingly glad that you are making it go so well."[14] The two discussed their progress on various equations in their series of letters.

Millikan remained interested in Fletcher's career and was ultimately influential in steering him toward communication acoustics. As a result of Millikan's recommendation, Fletcher was offered a research position with Western Electric in 1911. Frank Jewett, the president of the company and a friend of Millikan's, wanted someone familiar with the oil-drop work because he believed that developments in electron physics would eventually revolutionize the telephone industry. Fletcher turned down the opportunity, but Jewett was not easily deterred—each spring for the next five years, he renewed the offer.

Millikan periodically encouraged Fletcher to reconsider, finally writing in 1916, "At the present time, the biggest scientific problems in the United States are being tackled by the industrial research laboratories, particularly the General Electric laboratory and the research laboratory of the AT&T Company. I think myself that the outlook for the better men in these laboratories is just as good—in many respects better—than the outlook in many of our universities."[15] Fletcher, who had profound respect for Millikan's advice, finally accepted the job at Western Electric and moved to New York



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My dear Fletcher:

I am much interested in the results which you report in your recent letter. You are doing something which needed much to be done and which cannot be done too thoroughly. Your mean of N from your four drops comes out quite to suit me viz 6.08×10^{-23} but I take it you had to use my value of k to get it. Why don't you state your results in terms of Ne which can be compared as before with the electrolytic measurements?

Would you be good enough to let me know how your Ne comes out on these four drops? I should like to refer to your work in some lectures which I am to give at Columbia this Summer. I leave for New York next Friday so you may address me if you will at Columbia Univ'y New York City Dep't of Physics.

I will keep in mind what you say about the possibilities for the year following the present one & will talk the matter over with Jewett. Nichols has just gone down to New York to begin work with the A T & T Co.

Remember me heartily to Mrs Fletcher

Hastily yours

R A Millikan

One of the many letters that Millikan sent to Fletcher. This 1914 letter testifies to the easy rapport between the men and their continued, albeit distant and vague, collaboration on the oil-drop experiment. (Courtesy of L. Tom Perry Special Collections, Brigham Young University.)

City. There he enjoyed a distinguished career that spanned four decades, and he made great strides in the study of speech and hearing, achievements that led to his eventual appointment as director of physical research at Bell Telephone Laboratories. One scientist has described Fletcher as "the singular intellectual force in the development of present-day communications acoustics and telephony."[16]

Throughout their long careers, Fletcher and Millikan remained in contact, and at least 27 letters that passed between the men have survived. After receiving Fletcher's congratulations regarding the publication of *The Electron*, Millikan responded, "I am more than gratified that you should take the time to read the little book to which you contributed so largely."[17] A few years later Fletcher wrote to Millikan to congratulate him on receiving the Nobel Prize: "I feel sure that no other man has done so much for American science . . . because of the inspiration for doing greater research work created in all those who come in contact with you."[10] Millikan was obviously touched by the letter and replied, "No one knows my shortcomings as do the men like yourself with whom I have intimately worked, so that you may be assured that there are no congratulations which are more prized than those that come from such intimate friends."[17]

Although it is unfortunate that the two remembered details of their respective contributions to the oil-drop experiment differently, they did not allow those memories to impede their friendship. In 1948, nearly four decades after the successful development of the oil-drop method, Fletcher wrote, "Since our early associations at Ryerson I have watched and admired your wonderful accomplishments in science through the years. An even greater accomplishment is the influence for good that you as a public man have had upon society."[18] In his response, which is the last letter known to have passed between the men, Millikan confided, "I don't know of anybody who knows me better than you do."[18]

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