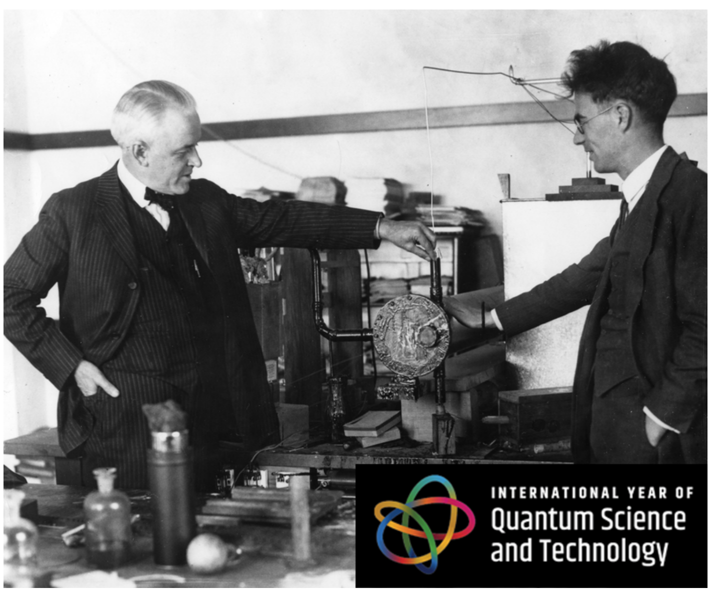
Quantum Milestones, 1916: Millikan's Measurement of Planck's Constant

The experiment provided further proof of the reality of photons, yet Millikan didn't accept their existence until later in his career.

By **Gerald Holton**

For the ***International Year of Quantum Science and Technology****, we are republishing stories on the history of quantum physics from the archives of* Physics Magazine *and* APS News*. The* ***original version of this story*** *was published in* Physics Magazine *on April 22, 1999.*

Robert A. Millikan's 1916 paper on the measurement of Planck's constant was dramatic in its time [**1**]. Today it lends itself to different, yet complementary, readings—the judgment by physicists that the work was worthy of the Nobel Prize and the historical insight it offers into the struggles Millikan faced accepting the very quantum theory he was validating.



Robert Millikan and Ira Bowen in the cosmic-ray laboratory at Caltech.
Credit: AIP Emilio Segrè Visual Archives

While it had been known for a long time that light falling on metal surfaces may eject electrons from them (the photoelectric effect), Millikan was the first to determine with great accuracy that the maximum kinetic energy of the ejected electrons obeys the equation Einstein had proposed in 1905: namely, $(1/2)mv^2 = h\nu - P$, where h is Planck's constant, ν the frequency of the incident light, and P is, in Millikan's words, "the work necessary to get the electron out of the metal." Millikan determined h to have the value 6.57×10^{-27} erg-second to "a precision of about 0.5 per cent," a value far better than had been obtained in any previous attempt.

Millikan's success was above all attributable to an ingenious device he termed "a machine shop *in vacuo*." A rotating sharp knife, controlled from outside the evacuated glass container by electromagnetic means, would clean off the surface of the metal used before exposing it to the beam of monochromatic light. The kinetic energy of the photoelectrons was found by measuring the potential energy of the electric field needed to stop them—here Millikan was able to confidently use the uniquely accurate value for the charge e of the electron he had established with his oil-drop experiment in 1913.

Shining through it all are Millikan's typical characteristics as experimenter and person: his penchant for experimenting in an area involving the hottest question of the day, his energetic

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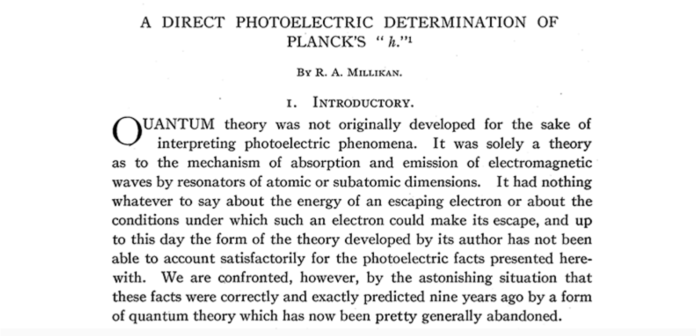

A DIRECT PHOTOELECTRIC DETERMINATION OF PLANCK'S "h."[1]

BY R. A. MILLIKAN.

I. INTRODUCTORY.

QUANTUM theory was not originally developed for the sake of interpreting photoelectric phenomena. It was solely a theory as to the mechanism of absorption and emission of electromagnetic waves by resonators of atomic or subatomic dimensions. It had nothing whatever to say about the energy of an escaping electron or about the conditions under which such an electron could make its escape, and up to this day the form of the theory developed by its author has not been able to account satisfactorily for the photoelectric facts presented herewith. We are confronted, however, by the astonishing situation that these facts were correctly and exactly predicted nine years ago by a form of quantum theory which has now been pretty generally abandoned.

Credit: R. A. Millikan [**1**]

persistence (this paper was the culmination of work he had begun in 1905), and his passion for obtaining results of great precision. In short, Millikan's experiment was a triumphant work, of highest importance in its day, and richly deserving to be cited as part of his Nobel Prize award in 1923, given "for his work on the elementary charge of electricity and the photoelectric effect."

To the historian, the volume in which Millikan's paper appeared shows that physics in America was still a mixed bag. Other papers show that the main attention at that time is the experimental part of science, in which Americans were long regarded as most interested and most competent. But the volume as a whole indicates that a good deal of the work going on in physics in this country in the early years of this century was still narrow and unambitious, even tending, for example, to descend to lengthy descriptions of improvements in basic equipment.

In an earlier paper (January 1916) in the same volume, Millikan writes in the very first sentence that "Einstein's photoelectric equation…cannot in my judgment be looked upon at present as resting upon any sort of a satisfactory theoretical foundation," even though "it actually represents very accurately the behavior" of photoelectricity. Indeed, Millikan's paper on Planck's constant shows clearly that he is emphatically distancing himself throughout from Einstein's 1905 attempt to couple photo effects with a form of quantum theory. What we now call the photon was, in Millikan's view, "[the] bold, not to say the reckless, hypothesis"—reckless because it was contrary to such classical concepts as light being a wave-propagation phenomenon. So Millikan's paper is not at all, as we would now expect, an experimental proof of the quantum theory of light.

In 1912 Millikan gave a lecture at the Cleveland meeting of the American Association for the Advancement of Science, meeting jointly with the American Physical Society, in which he clearly regarded himself as the proper presenter of Planck's theory of radiation. With his usual self-confidence, Millikan confessed that a corpuscular theory of light was for him "quite unthinkable," unreconcilable, as he saw it, with the phenomena of diffraction and interference. In short, Millikan's classic 1916 paper was purely intended to be the verification of Einstein's equation for the photoelectric effect and the determination of h, without accepting any of the "radical" implications that today seem so natural.

When Millikan's Nobel Prize came to pass, his Nobel address contained passages that showed his continuing struggle with the meaning of his own achievement: "This work resulted, contrary to my own expectation, in the first direct experimental proof…of the Einstein equation and the first direct photoelectric determination of Planck's h."

Yet it is difficult to find any published basis in Millikan's experimental papers of that struggle with his own expectations. His internal conflict was of a somewhat different sort; while Millikan conceded that Einstein's photoelectric equation was "experimentally established…the conception of localized light quanta out of which Einstein got his equation must still be regarded as far from being established." Ironically, it had been Millikan's experiment that convinced the experimentalist-inclined committee in Stockholm to admit Einstein to that select circle in 1922.

One final irony: In 1950, at age 82, Millikan published his autobiography, with Chapter 9 entitled simply "The Experimental Proof of the Existence of the Photon—Einstein's Photoelectric Equation." By then, Millikan had of course come to terms with the photon. Moreover, he had evidently changed his mind about what he had done around 1916, for now he wrote that as the experimental data became clear in his lab, they "proved simply and irrefutably, I thought, that the emitted electron that escapes with the energy $h\nu$ gets that energy by the direct transfer of $h\nu$ units of energy from the light to the electron, and hence scarcely permits of any other interpretation than that which Einstein had originally suggested, namely that of the semicorpuscular or photon theory of light itself."

In the end, Millikan reimagined the complex personal history of his splendid experiment to fit the simple story told in so many of our physics textbooks.

Gerald Holton is professor of physics and professor of history of science, Harvard University.

REFERENCES

1. R. A. Millikan, "A direct photoelectric determination of Planck's '*h*'," **Phys. Rev. 7, 355 (1916).**