Boston QuarkNet Workshop Photons: Photoelectric Effect

August 3, 2021

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Who first investigated what came to be known as the photoelectric effect?

A. Michael Faraday

B. James Maxwell

C. Heinrich Hertz

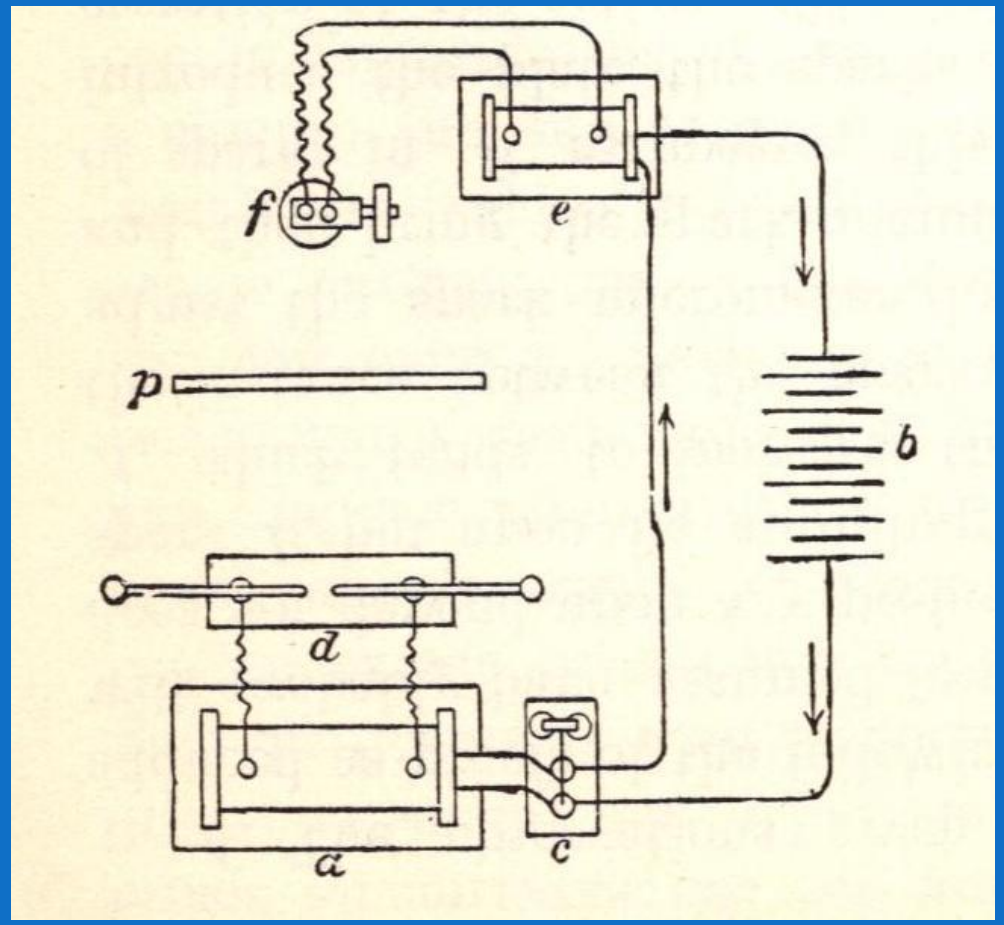
D. Philipp Lenard

E. Albert Einstein

Heinrich Hertz (1857-1894)

- In 1886 Hertz began to investigate electromagnetic effects produced by oscillating sparks generated by an induction coil.
- Modern version of a Hertz experiment
- Hertz noticed that the secondary spark between electrodes of his detector was more easily produced if the primary spark was visible from the secondary electrodes.
- Why was that?

Hertz's Experimental Results (1887)



- Effect from spark spreads in straight lines.
- Effect inhibited by glass and other materials in plate (*p*).
- Effect transmitted by quartz, gypsum.
- Effect primarily active at negative secondary electrode.
- Effect can be reflected from glass and other surfaces.
- Effect refracted more strongly than violet light in quartz prism.

Conclusion

“According to the results of our experiments, ultraviolet light has the property of increasing the sparking distance of the discharge of an induction coil.”

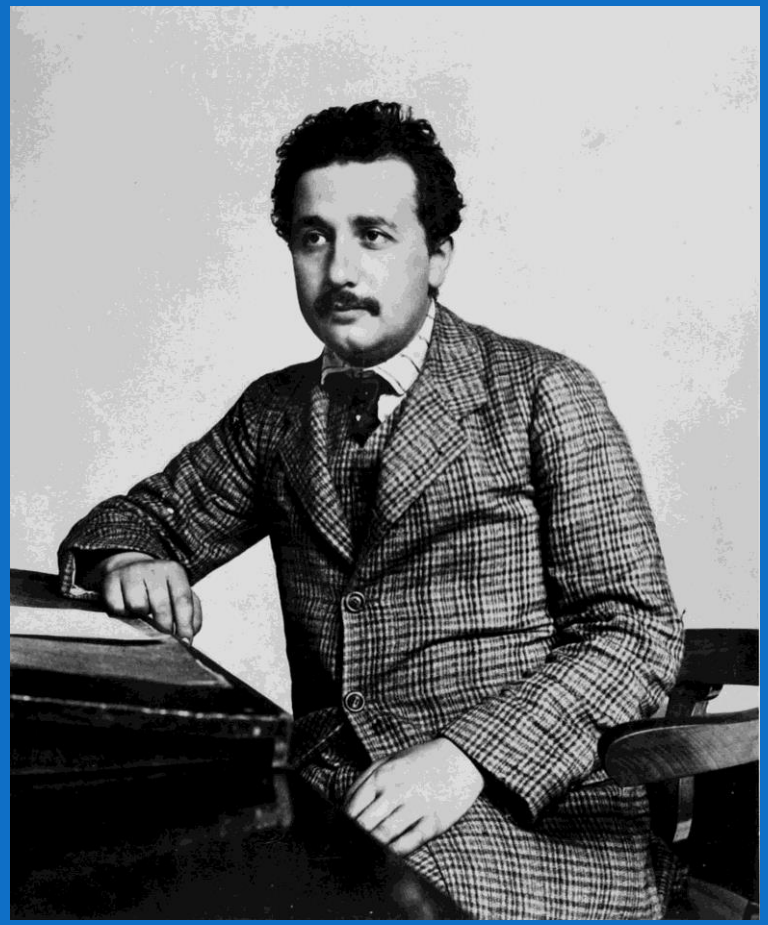
H. Hertz, *Electric Waves: Being Researches on the Propagation of Electric Action with Finite Velocity Through Space* (1893), (D. E. Jones, trans.), Dover Publications, Inc. , New York, 1962, p. 78.

Do you recognize the name Philipp Lenard?

Philipp Lenard (1862-1947)

- 1892-1894 – assistant to Hertz
- 1899 – electrons are ejected in photoelectric effect
- 1902 – minimum frequency of light needed to produce photoelectrons
- Ejected electron speed increases as incident light frequency increases, but is independent of intensity
- Number of ejected electrons proportional to light intensity if $f > f_{min}$
- 1905 – Nobel Prize in Physics for work on cathode rays

Albert Einstein (1879-1955)



- “[W]hen one attempts to explain the photoelectric phenomena, … one can conceive of the ejection of electrons by light in the following way. Energy quanta penetrate into the surface layer of the body, and their energy is transformed, at least in part into kinetic energy of electrons. The simplest way to imagine this is that a light quantum delivers its entire energy to a single electron; we shall assume that this is what happens.”
Ann. Physik **17**, 132 (1905); trans. A.B. Aarons and M. B. Peppard.

Two Explanations

Einstein

- Light Quantum→Electron Energy
- $hf = W_{metal} + m_e v_e^2/2$

hf = light quantum energy
h = Planck's constant
f = light frequency

W_{metal} = work function of metal
= energy required to remove electron from metal surface

$m_e v_e^2/2$ = electron kinetic energy

Lenard

- "[L]ight waves cause the interior of the metal atoms in the plate to vibrate….If the co-vibration of a negative quantum [electron] in the atom with the light waves becomes too violent, the quantum [electron] escapes from the atom."
- "[The electron] energy at escape does not come from the the light at all, but from the interior of the particular atom. The light only has an initiating action, rather like a fuse in firing a loaded gun."
P. Lenard, Nobel Lecture, May 1906.

Sad End

- After initially praising Einstein for his photoelectric theory, Lenard grew jealous of the recognition that Einstein received for the theory.
- He became a vocal opponent of Einstein's relativity theory and "Jewish" science. Lenard advocated "German" science and joined the Nazi party.
- Lenard was appointed Chief of Aryan Physics under Hitler.
- He died, a bitter old man, two years after the end of WW II.

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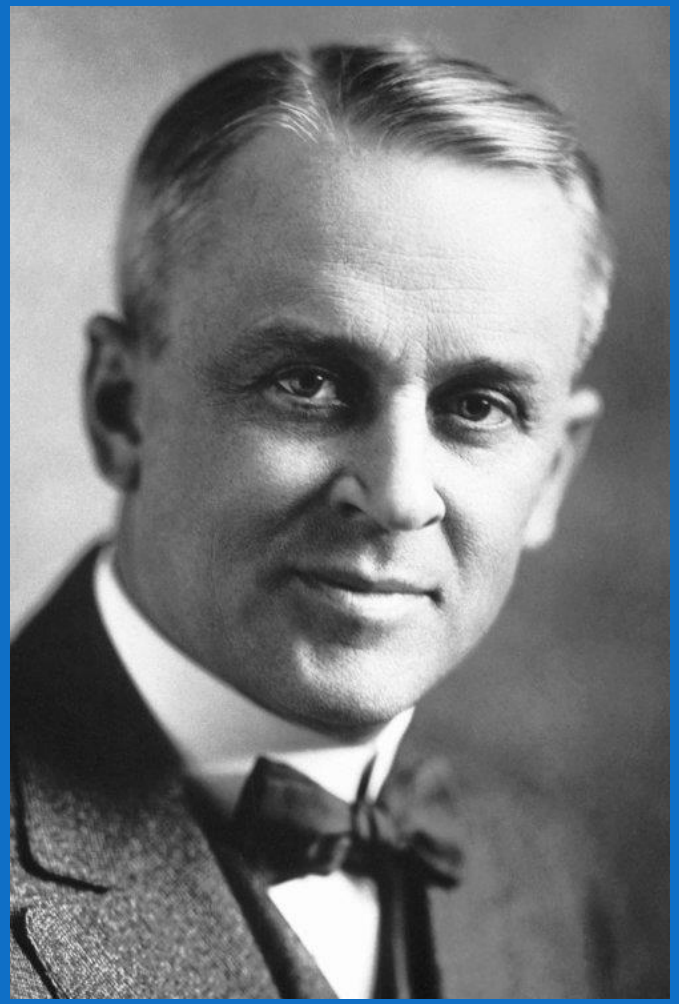
Max Tegmark (cosmologist at MIT) translated the full version of the award citation:
"THE ROYAL SWEDEISH ACADEMY OF SCIENCE has at its meeting on November 9, 1922, in accordance with the regulations in the November 27, 1895, will of ALFRED NOBEL decided to, independently of the value that, after possible confirmation, may be attributed to the relativity and gravitation theory, award the prize that for 1921 is given to the person who within the domain of physics has made the most important discovery or invention, to ALBERT EINSTEIN for his contributions to theoretical physics, especially his discovery of the photoelectric effect." (Tegmark, *Our Mathematical Universe*, p. 244.)

For what work was Robert Millikan cited in the award of his Nobel Prize in Physics in 1923?



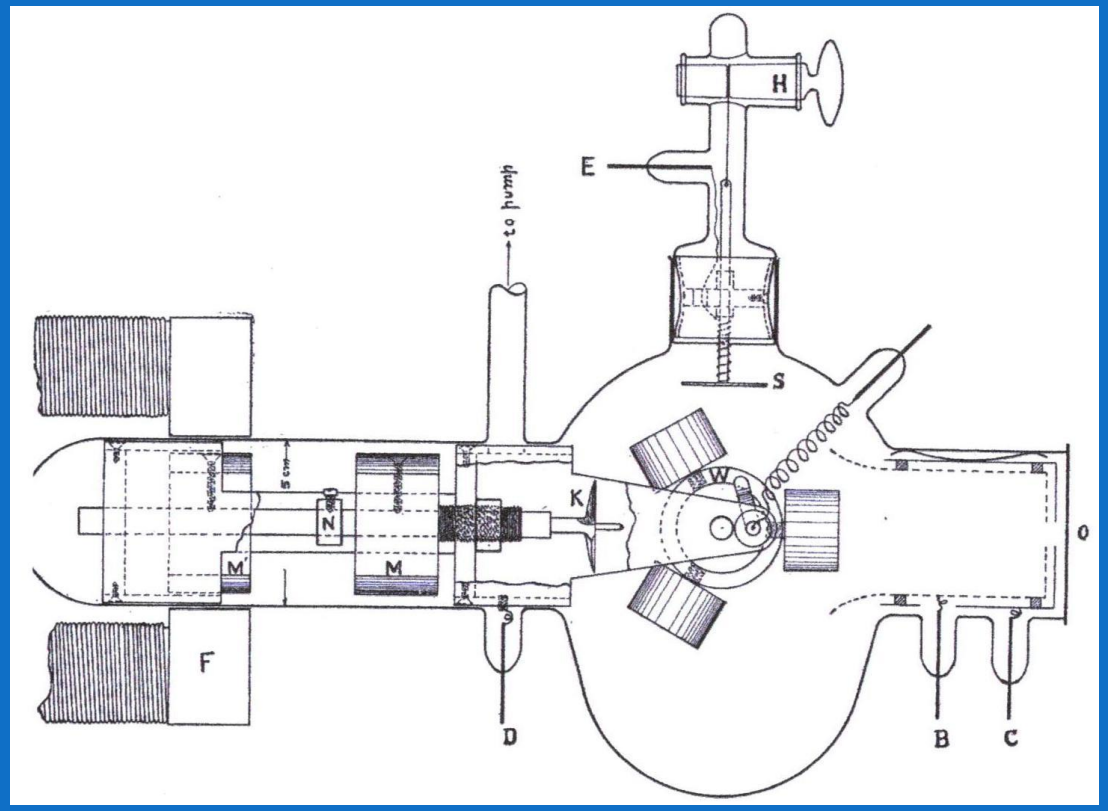
Robert Millikan was awarded of the Nobel Prize in Physics in 1923 “for his work on the elementary charge of electricity and on the photoelectric effect.”

R. A. Millikan, “A Direct Photoelectric Determination of Planck’s ‘*h*,’” *Phys. Rev.* **7** (1916), 355-390.

From introduction:
“Einstein made the first coupling of photo effects … with any form of quantum theory by bringing forward the bold, not to say reckless, hypothesis of an electro-magnetic light corpuscle of energy $h\nu$ [ν = frequency], which energy was transferred upon absorption to an electron. This hypothesis may well be called reckless,
first because an electromagnetic disturbance which remains localized in space seems a violation of the very conception of an electromagnetic disturbance, and *second* because it flies in the face of the thoroughly established facts of interference.” [emphasis added]

With this skeptical attitude, Millikan set out to examine Einstein’s photoelectric equation.

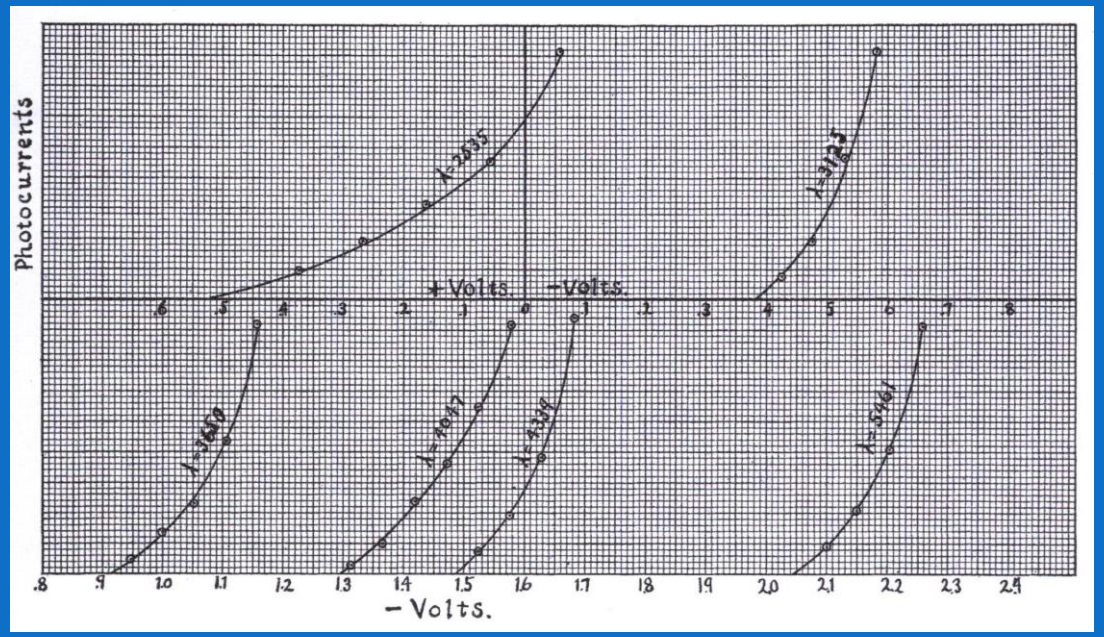
Millikan's "machine shop in vacuo"



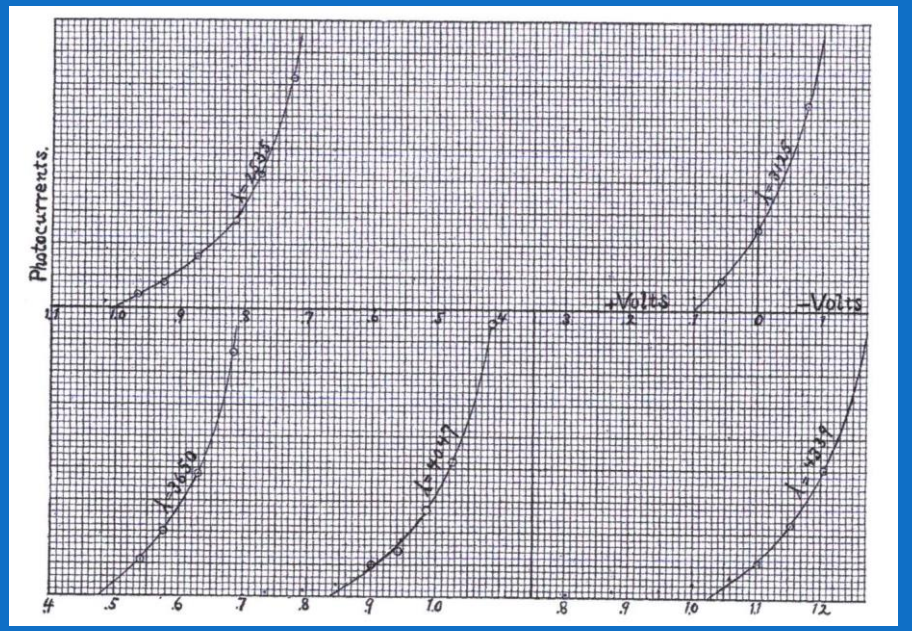
- W = wheel with alkali metal cylinders
- K = knife for shaving metal to obtain a clean surface
- S = copper plate for measuring contact potential
- B, C = Faraday cylinder for collecting charge
- O = entrance for incident light from a mercury vapor lamp

Data
Millikan extrapolated his measurements to the voltage for zero current

Sodium



Lithium



Millikan's Conclusion

"Despite the apparently complete success of the Einstein equation, the physical theory of which it was designed to be the symbolic expression is…untenable."

"But how else can the equation be obtained?"

If the Einstein conception is abandoned, "*there is no alternative but to assume that the corpuscles [electrons] which are ejected are already possessed of an energy almost equal to* $h\nu$" (italics in original).

Nobel Lecture (May 1924): "[I]t is not merely the Einstein equation which is having extraordinary success at the moment, but the Einstein conception as well. But until it can account of the facts of interference…, we must withhold our full assent."