Joint Quantum Institute

Exploring Quantum Physics

Coursera, Spring 2013 Instructors: Charles W. Clark and Victor Galitski

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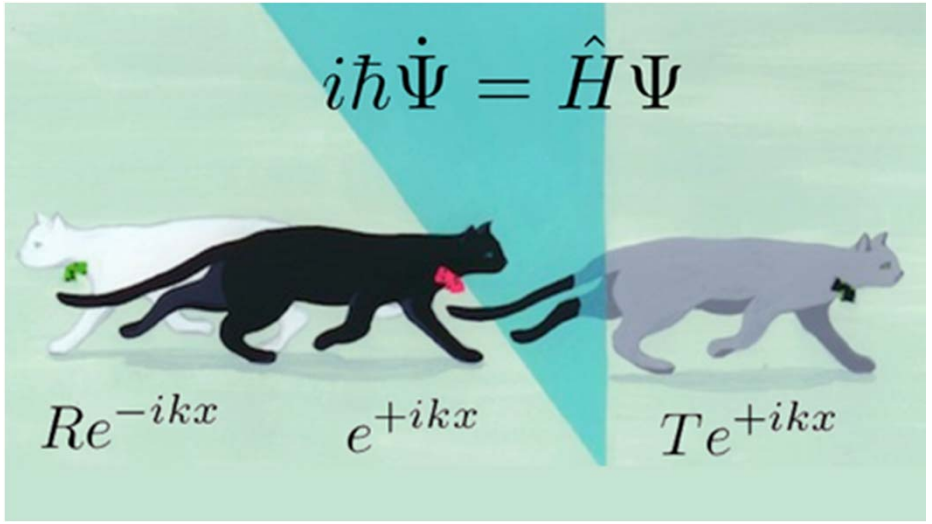
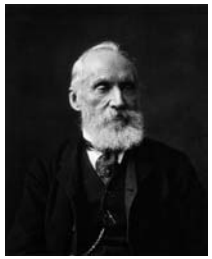
Wave-function and Schrödinger equation

Part II: Pioneering experiments



Classical "theory of everything"

- Pre-20th century outlook, two examples:
  - Albert Michelson (1894): *"...The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote..."*
  - Lord Kelvin (1900): *"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement."*
- A few elephants in the room (early 20th century)
  - Black-body radiation
  - Quantization of atomic spectra
  - The photoelectric effect
  - Accident at Bell Labs shows electrons behave like waves.



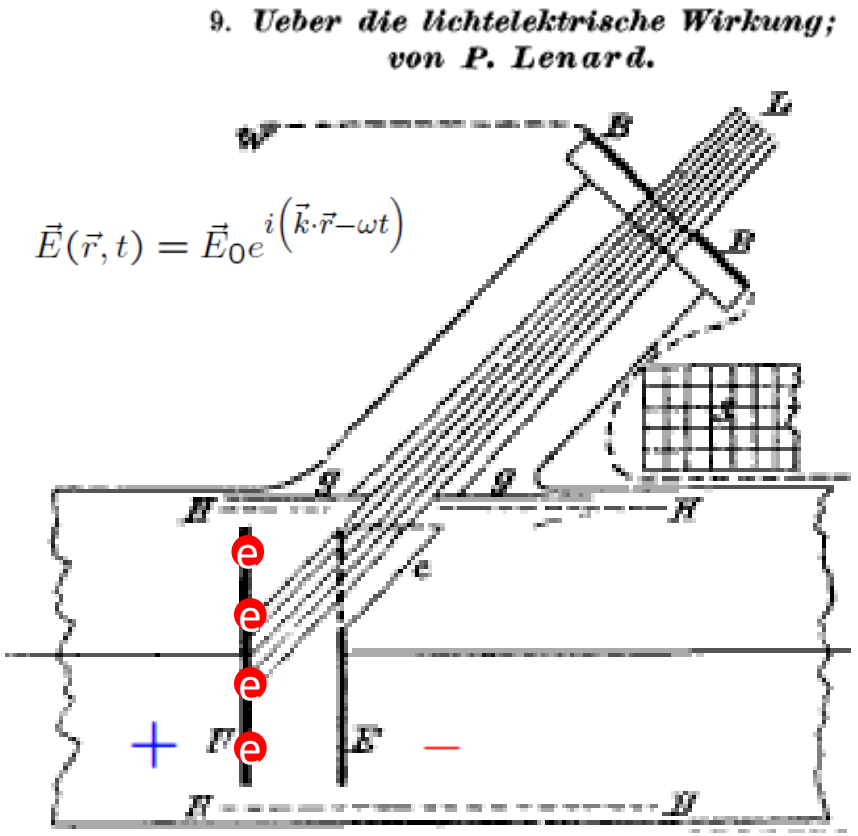
The photoelectric effect

Classical theory predicts that increasing the **<u>intensity</u>** of the light should lead to more energetic photoelectrons. Light of any frequency should be able to kick electrons out of the metal plate.

Experiment showed exactly the opposite:

1. The energy of electrons did <u>not</u> depend on the intensity.
2. <u>No</u> photoelectrons were produced if the frequency was smaller than a critical value.

$$\vec{E}(\vec{r},t) = \vec{E}_0 e^{i\left(\vec{k}\cdot\vec{r}-\omega t\right)}$$

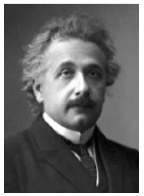


Einstein's explanation: photons

ANNALEN
DER
PHYSIK.

LEIPZIG, 1905.

6. *Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt;*
von A. Einstein.



Concerning an Heuristic Point of View Toward the Emission and Transformation of Light
A. Einstein
Bern, 17 March 1905

"The usual conception that the energy of light is continuously distributed over the space through which it propagates, encounters very serious difficulties when one attempts to explain the photoelectric phenomena, as has been pointed out in Herr Lenard's pioneering paper.

According to the concept that the incident light consists of energy quanta ..., however, 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…"

Einstein's explanation: photons

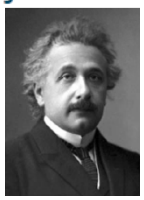
- Energy of a photon with the wave-length, λ

$$E = \frac{hc}{\lambda} = \hbar\omega$$

- The Planck constant

$$h = 2\pi\hbar = 6.626 \times 10^{-34}\,\mathrm{J}\cdot\mathrm{s}$$

The Nobel Prize in Physics 1921
Albert Einstein



The Nobel Prize in Physics 1921 was awarded to Albert Einstein *"for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect"*.