2304104: GEN PHYS II
2304154: PHYS ELEC ENGS

Update: April 25, 2022

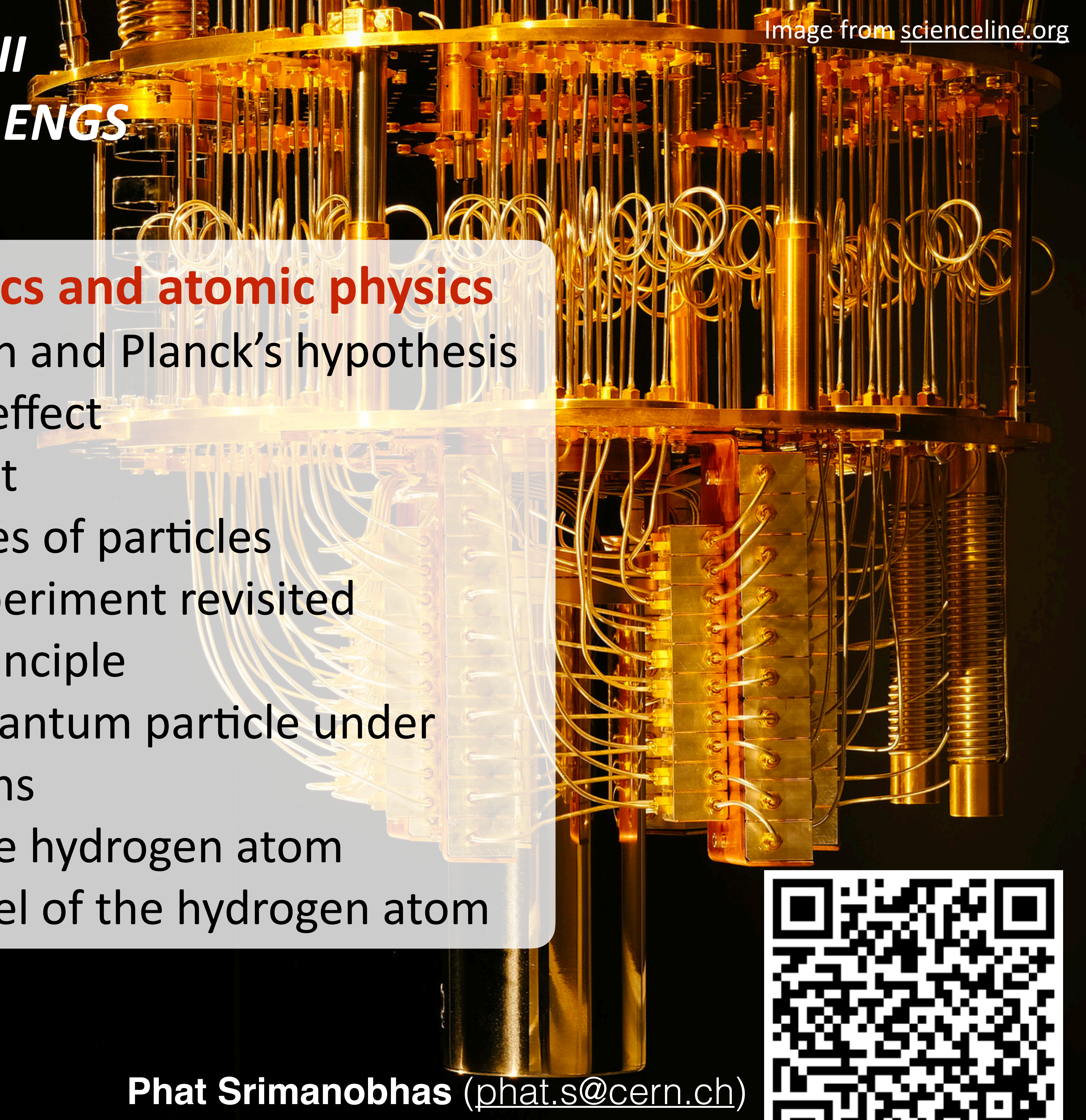

Image from scienceline.org

Quantum mechanics and atomic physics

- Blackbody radiation and Planck’s hypothesis
- The photoelectric effect
- The Compton effect
- The wave properties of particles
- The double-slit experiment revisited
- The uncertainty principle
- Analysis model: quantum particle under boundary conditions
- Bohr’s model of the hydrogen atom
- The quantum model of the hydrogen atom

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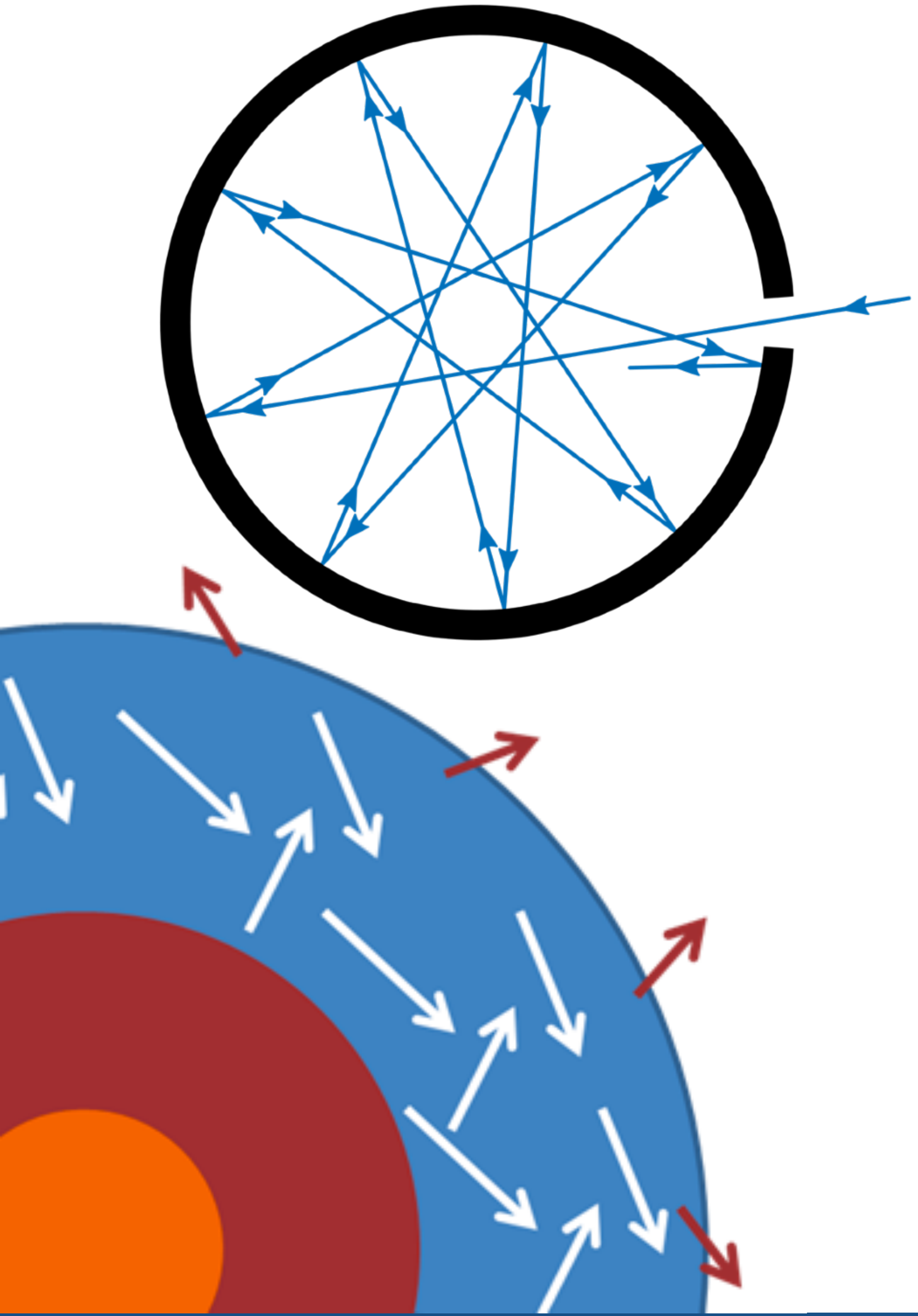
https://twiki.cern.ch/twiki/bin/view/Main/PhatSrimanobhasTeaching

Blackbody and blackbody radiation



Blackbody is an object or system which absorbs all radiation incident upon it.

Blackbody radiation is a blackbody which re-radiates energy. The radiation depends on the temperature of the cavity wall, and not on the material of which the walls are made.

Example: Cavity with a hole, stars (e.g. Sun), hot charcoal.

The wavelength distribution of radiation from cavities was studied experimentally in the late 19th century. The following two consistent experimental findings were seines significant.

Blackbody and blackbody radiation

- The total power of the emitted radiation increases with temperature [Stefan’s law]

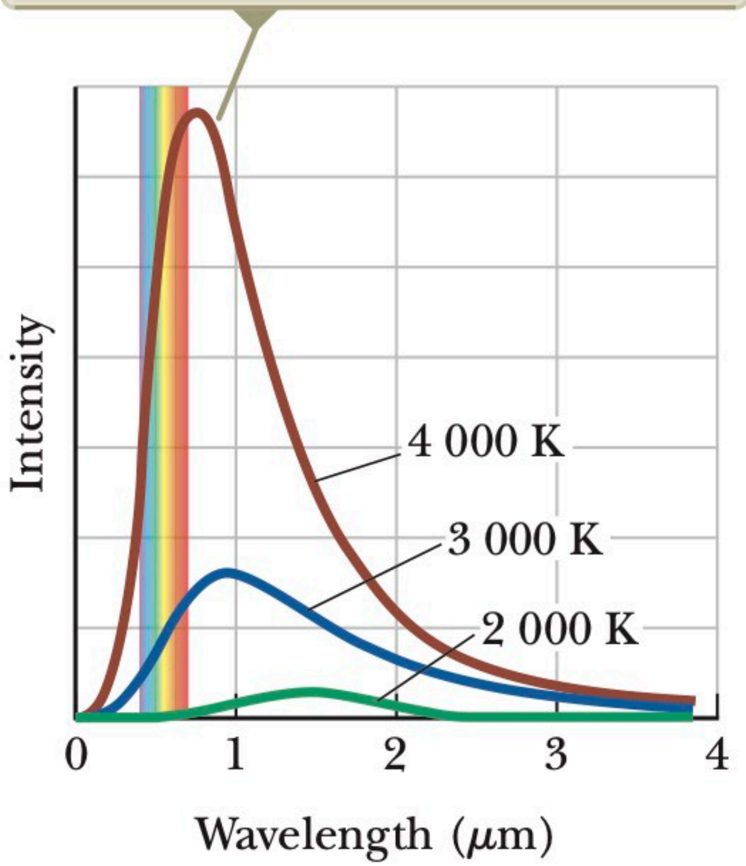

The 4 000-K curve has a peak near the visible range. This curve represents an object that would glow with a yellowish-white appearance.

Figure 40.3 Intensity of blackbody radiation versus wavelength at three temperatures. The visible range of wavelengths is between 0.4 μm and 0.7 μm. At approximately 6 000 K, the peak is in the center of the visible wavelengths and the object appears white.

Blackbody and blackbody radiation

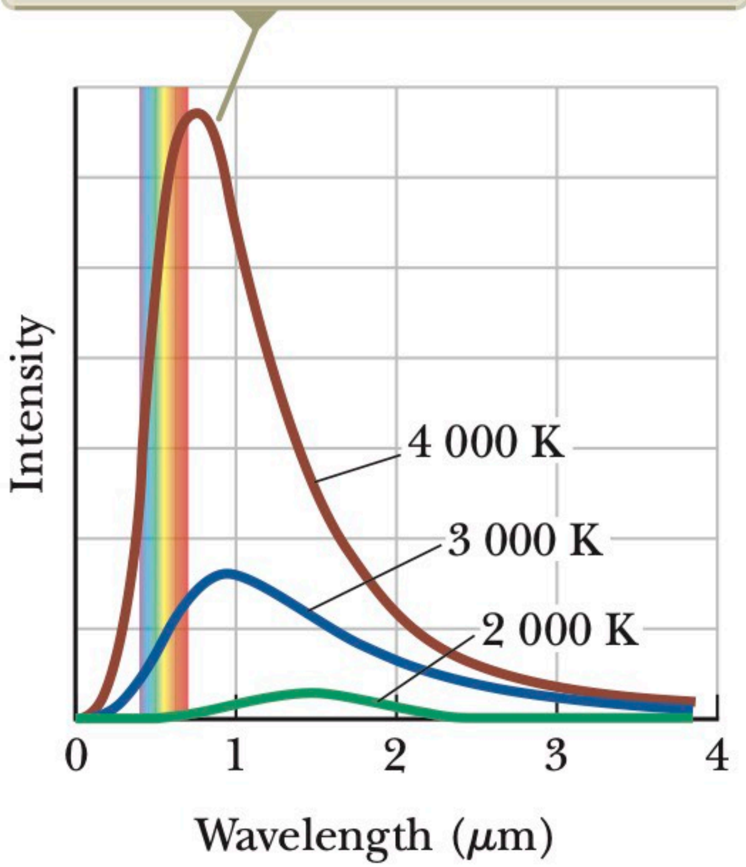


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Figure 40.3 Intensity of blackbody radiation versus wavelength at three temperatures. The visible range of wavelengths is between 0.4 μm and 0.7 μm. At approximately 6 000 K, the peak is in the center of the visible wavelengths and the object appears white.

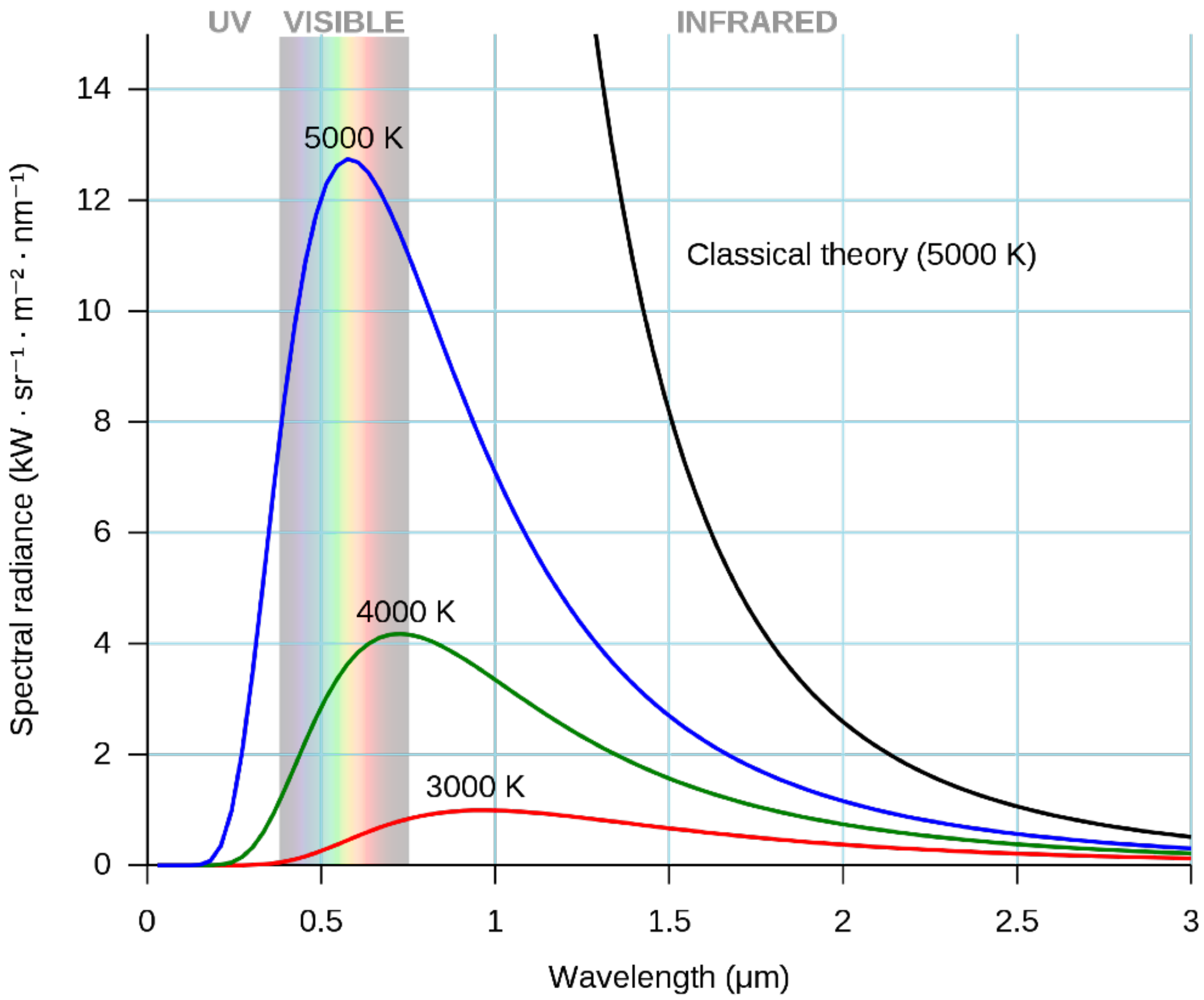
- The peak of the wavelength distribution shifts to shorter wavelengths as the temperature increases [Wien’s displacement law]

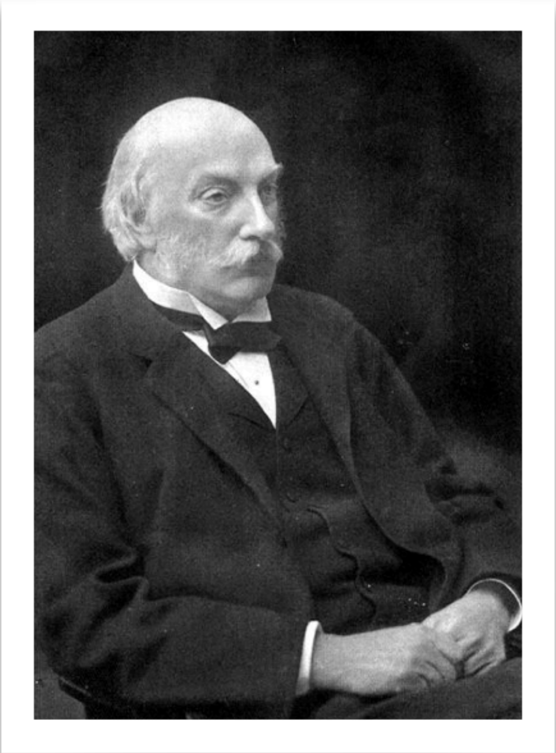
Ultraviolet catastrophe

Looked for a theory to describe blackbody radiation

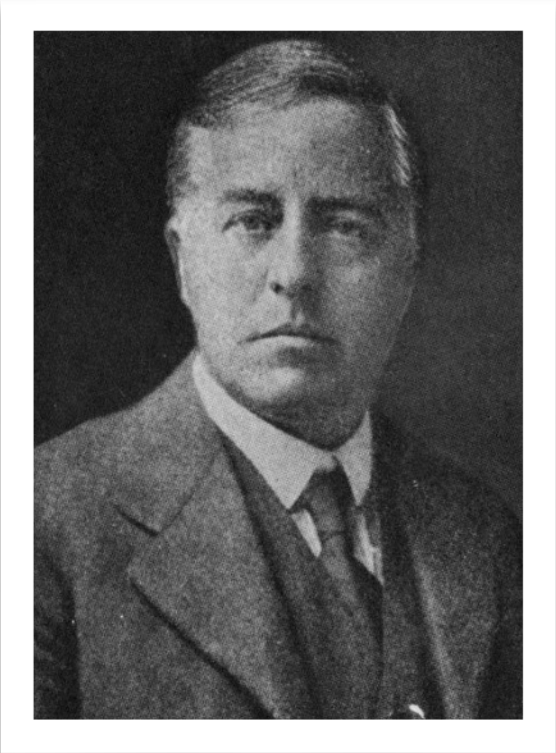
- Temperature dependence: Stefan's law
- Shift of the peak: Wien's displacement law

However, classical theory (Rayleigh–Jeans law) of blackbody radiation failed.





The Lord Rayleigh

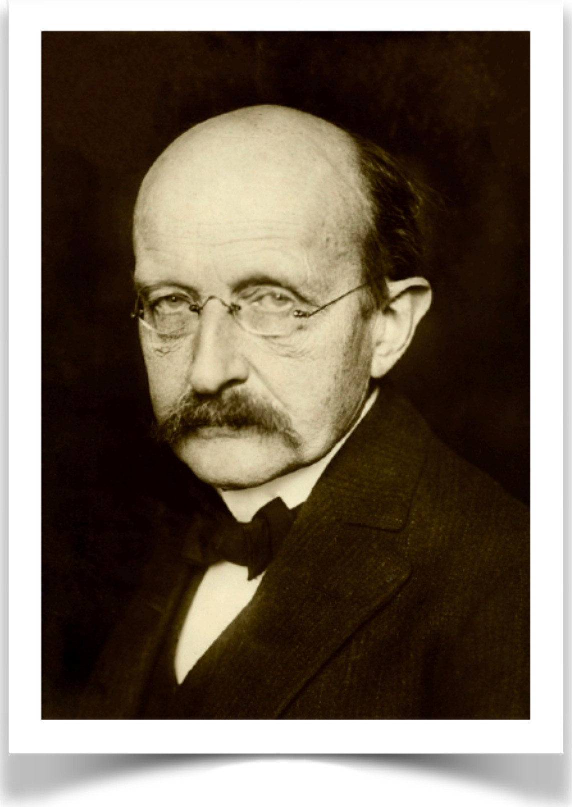


Sir James H. Jeans

$$I(\lambda, T) =$$

Ad hoc assumption by Plank

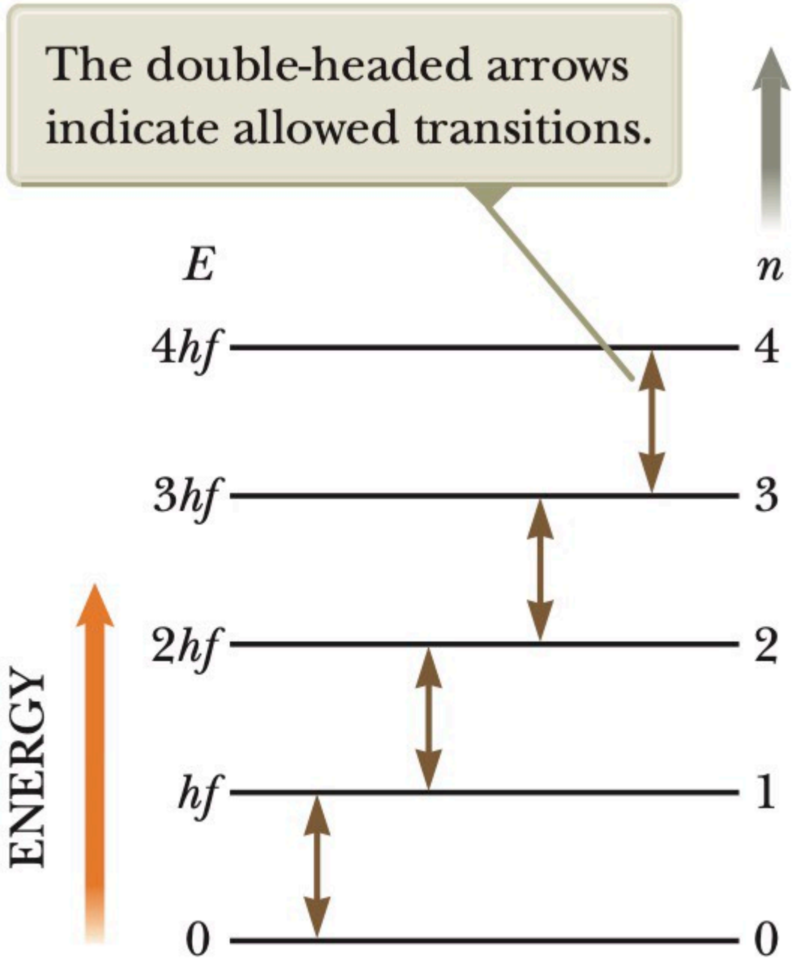
In 1900, Max Planck developed a theory of blackbody radiation which is agreement with experimental results at all wavelengths.



Max Planck

Assumption:

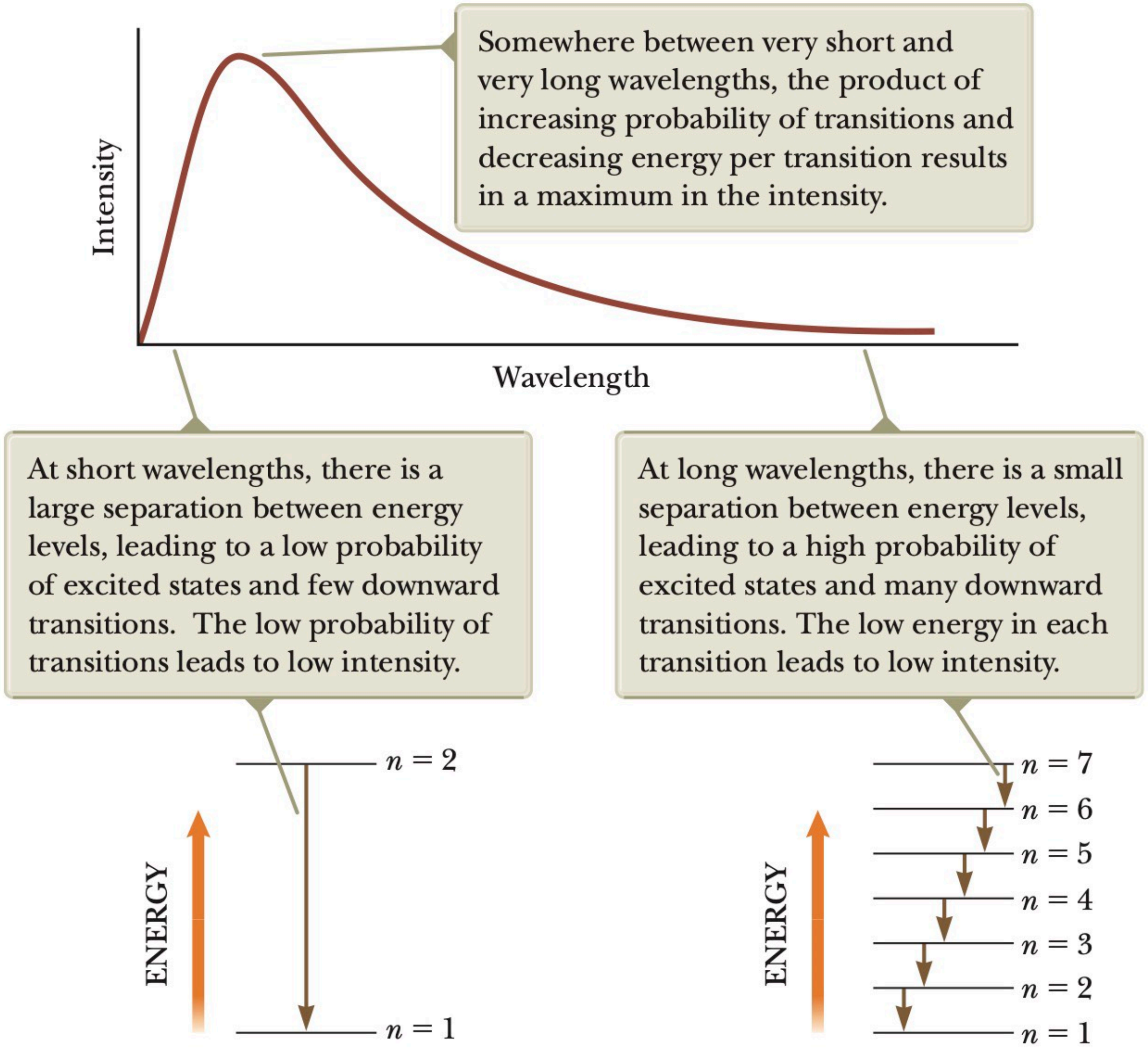
- Cavity radiation came from atomic oscillators in the cavity walls.
- Energy of an oscillator have only certain discrete values.
- Oscillators emit or absorb energy when making transition from one quantum state to another.
  - Energy of each oscillator can have only discrete value ==> Quantized
  - Each discrete energy value corresponds to a different quantum state.


The double-headed arrows indicate allowed transitions.

Ad hoc assumption by Plank

$$\boxed{I(\lambda, T) =}$$

It can be shown that, in the limit of high temperatures or long wavelengths, Planck's blackbody formula can be reduced to Rayleigh–Jeans expression.

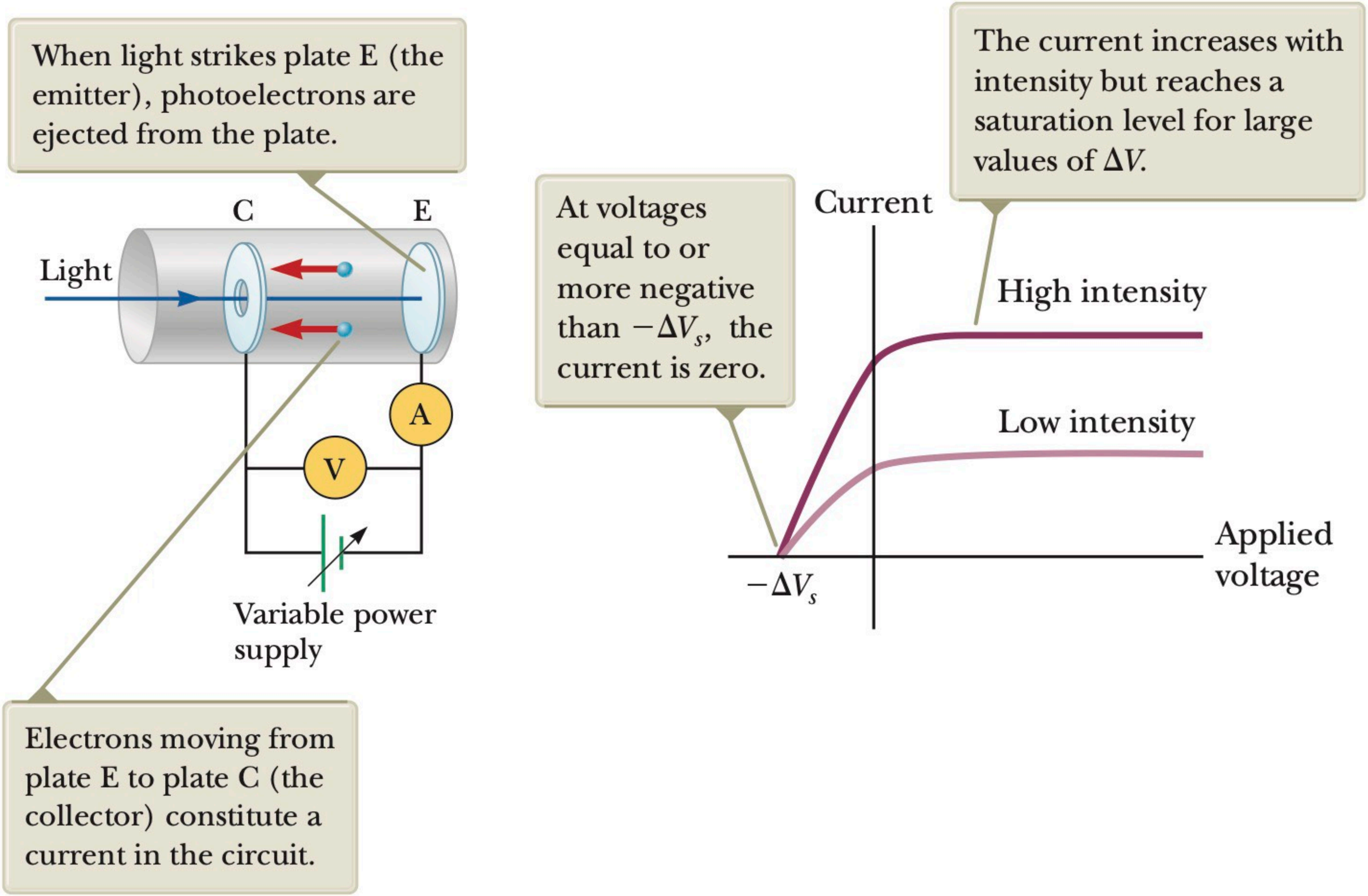


Somewhere between very short and very long wavelengths, the product of increasing probability of transitions and decreasing energy per transition results in a maximum in the intensity.

At short wavelengths, there is a large separation between energy levels, leading to a low probability of excited states and few downward transitions. The low probability of transitions leads to low intensity.

At long wavelengths, there is a small separation between energy levels, leading to a high probability of excited states and many downward transitions. The low energy in each transition leads to low intensity.

The photoelectric effect



When light strikes plate E (the emitter), photoelectrons are ejected from the plate.

Electrons moving from plate E to plate C (the collector) constitute a current in the circuit.

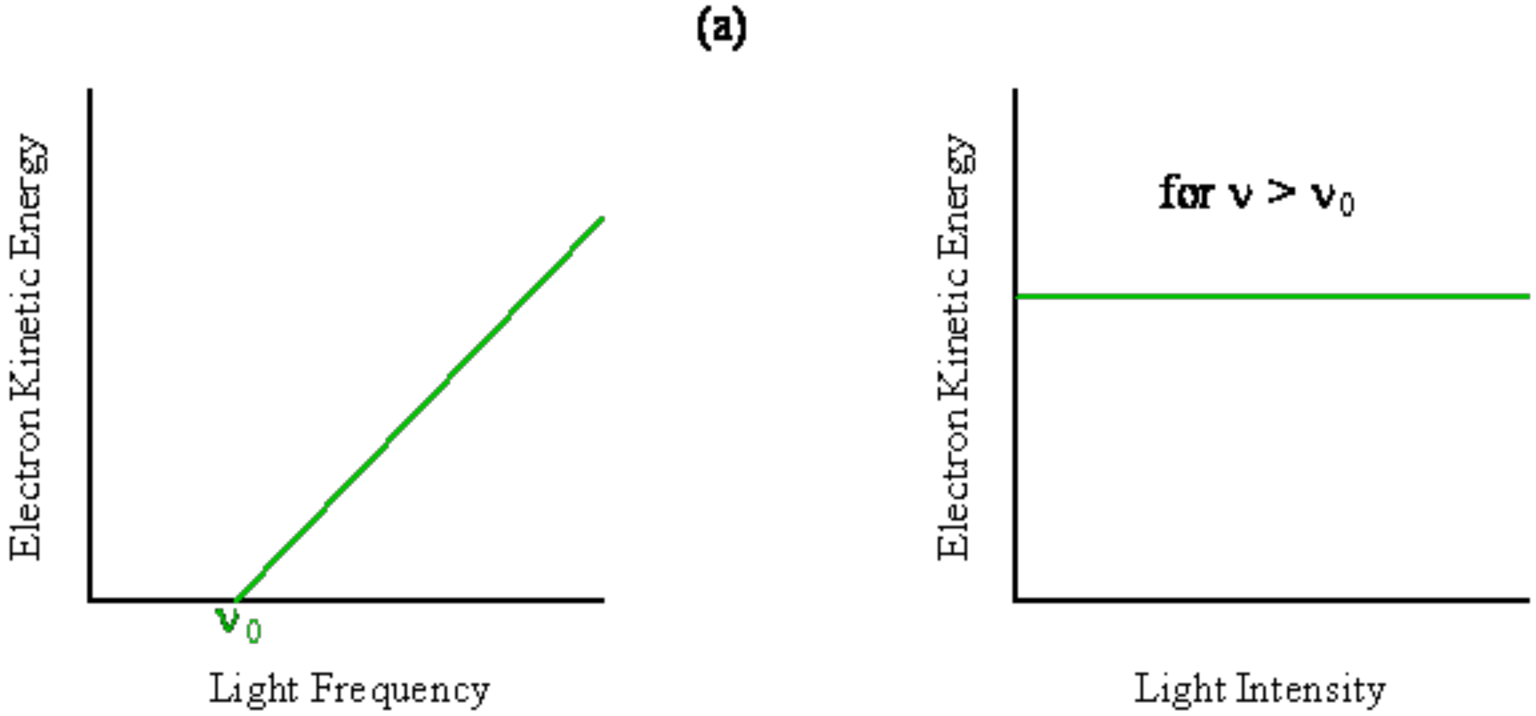
At voltages equal to or more negative than $-\Delta V_s$, the current is zero.

The current increases with intensity but reaches a saturation level for large values of ΔV.

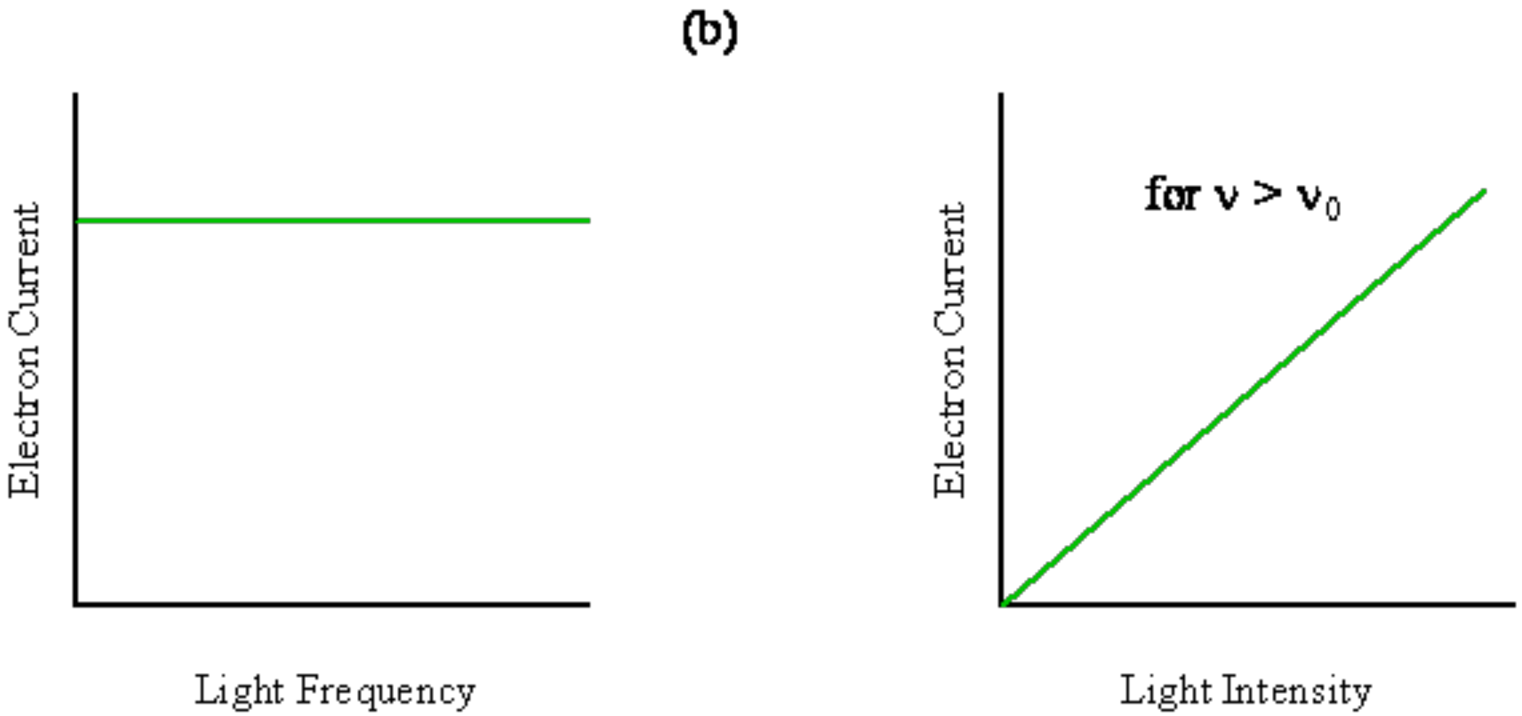
The photoelectric effect

Several features of the photoelectric effect:

(a) The kinetic energy of any single emitted electron increases linearly with frequency above some threshold value and is independent of the light intensity.

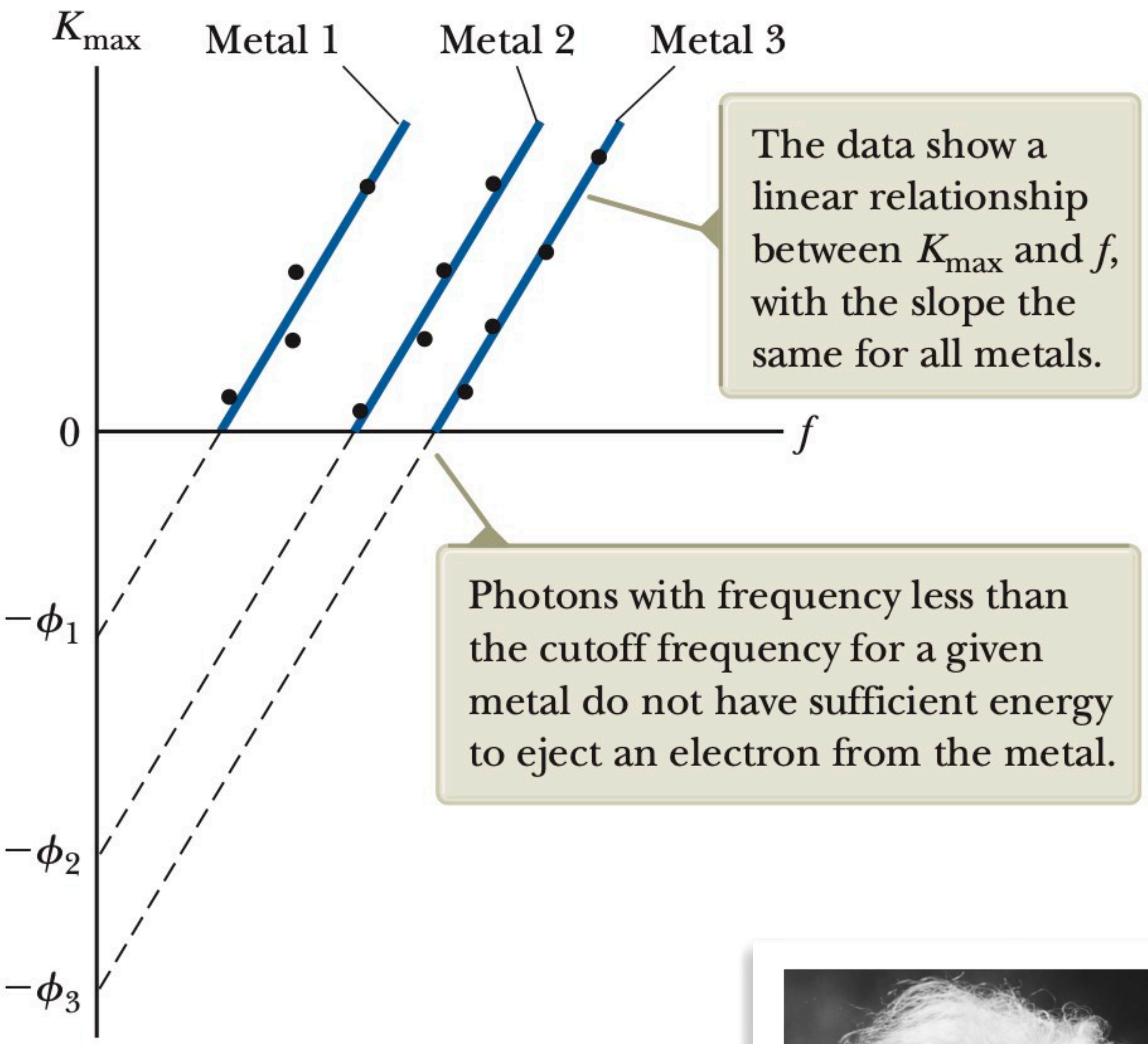


(b) The number of electrons emitted per second (i.e. the electric current) is independent of frequency and increases linearly with the light intensity.



The photoelectric effect

By varying frequency of light, and measure maximum K.E. on different metals, we get the result as in figure. ***How should you next?***

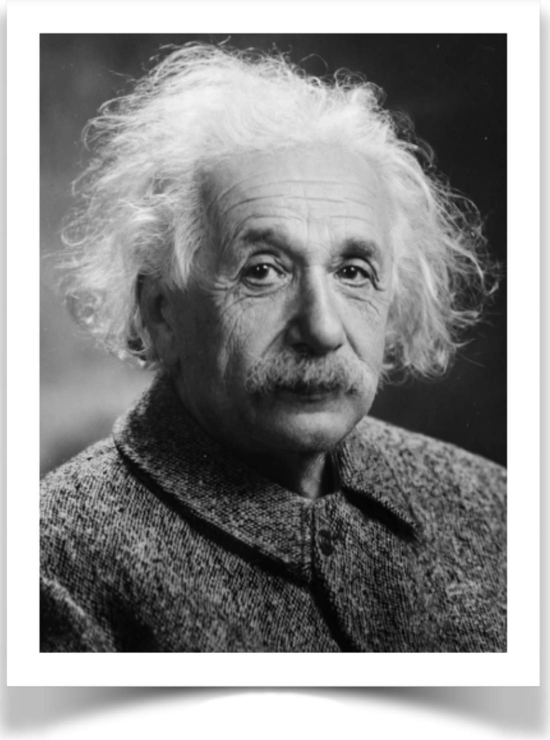


The data show a linear relationship between K_{max} and f, with the slope the same for all metals.

Photons with frequency less than the cutoff frequency for a given metal do not have sufficient energy to eject an electron from the metal.

In 1905, Einstein re-derived Planck's results by assuming the oscillations of the electromagnetic field were themselves quantized. In other words, he proposed that quantization is a fundamental property of light and other electromagnetic radiation, which led to the concept of photons.

Each photon has an energy $E = hf$ and each moves in a vacuum at the speed of light.



Albert Einstein

The photoelectric effect

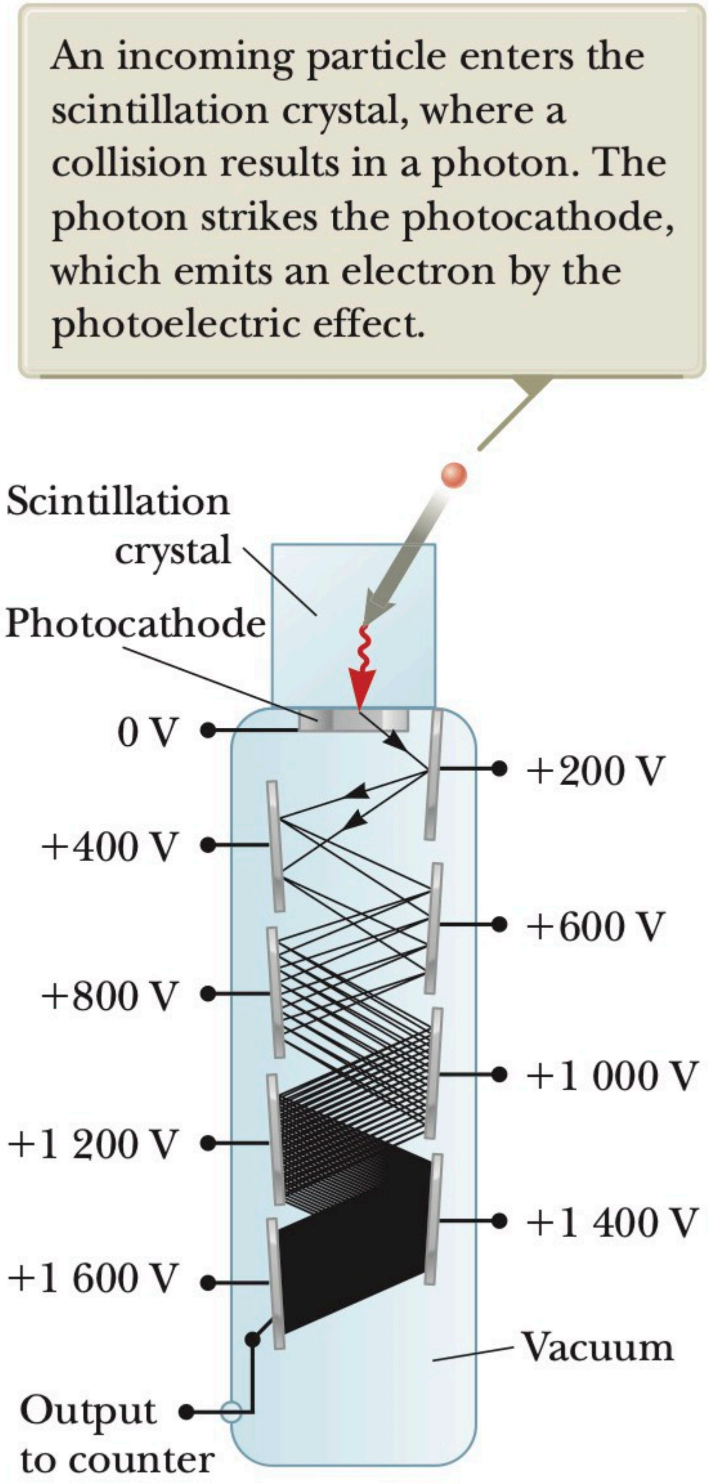
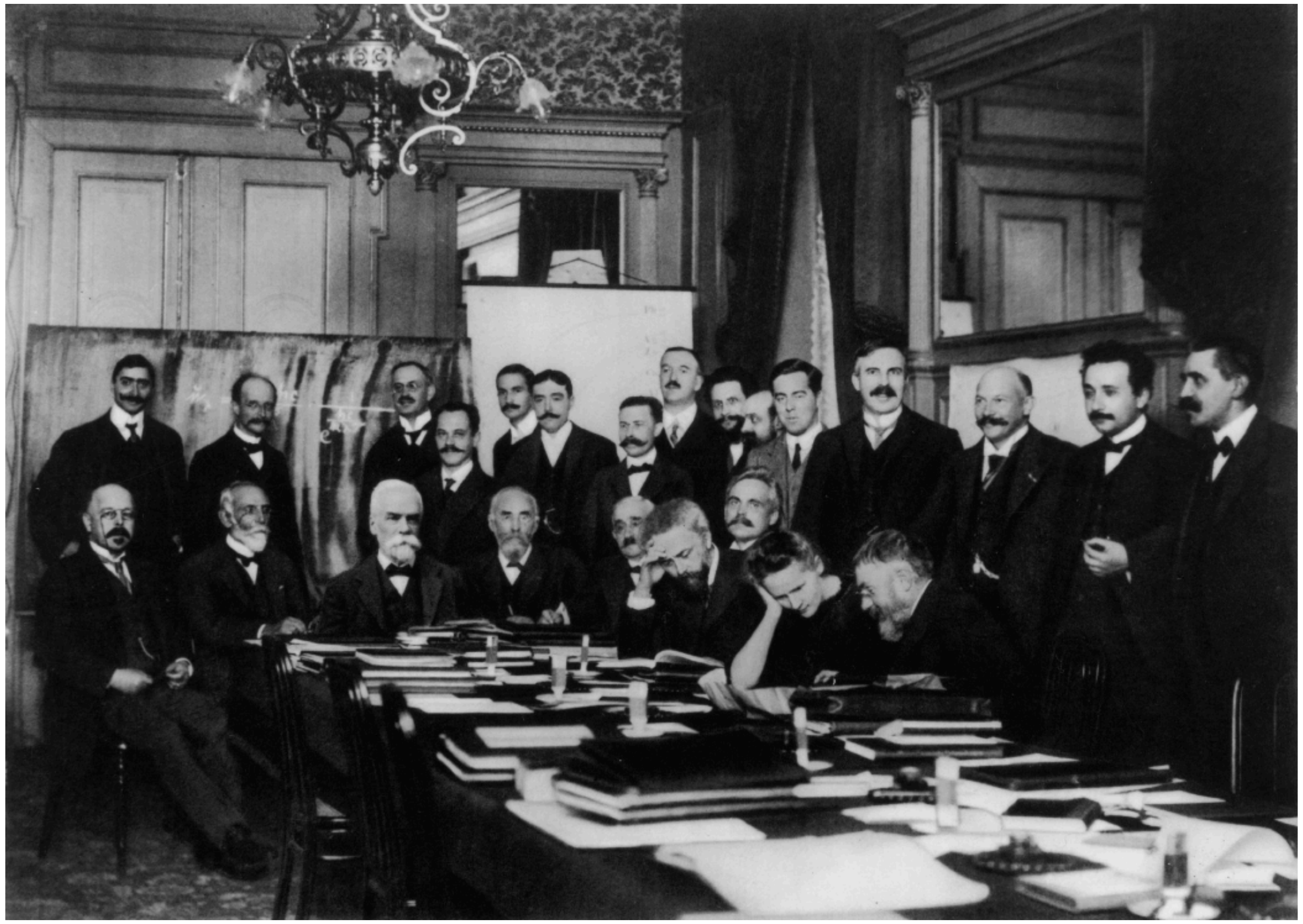


Figure 40.12 The multiplication of electrons in a photomultiplier tube.

Today, the photoelectric effect is used in the operation of photomultiplier tubes. This device ais extremely sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum. These detectors can multiply the current produced by incident light by as much as 100 million times.

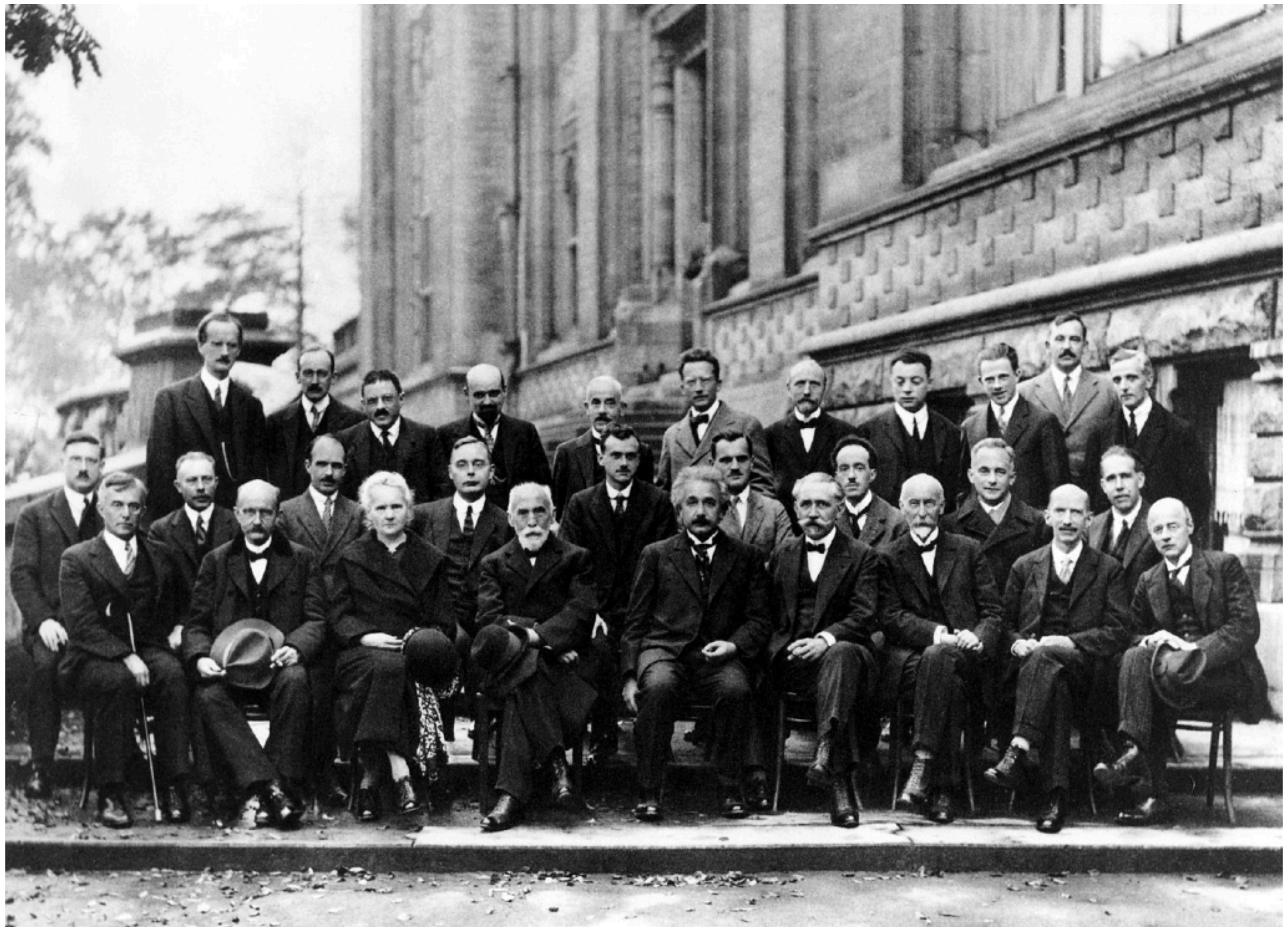
Solvay Conference



1st Solvay Conference in 1911

La théorie du rayonnement et les quanta

The theory of radiation and quanta

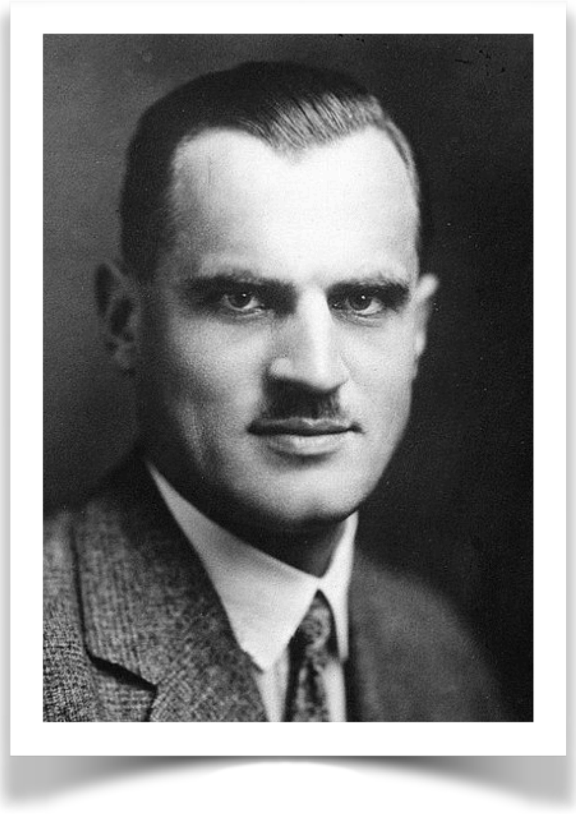


5th Solvay Conference in 1927

Electrons et photons

Electrons and photons

The Compton effect

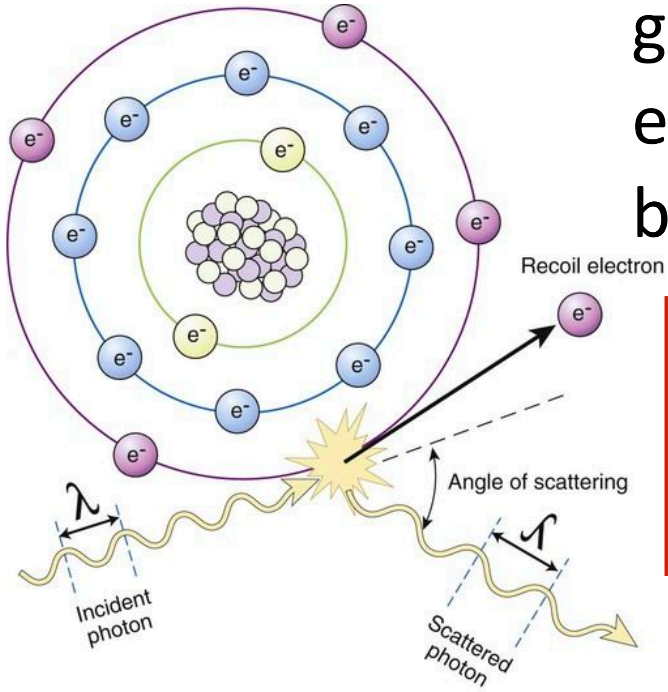


Arthur Compton

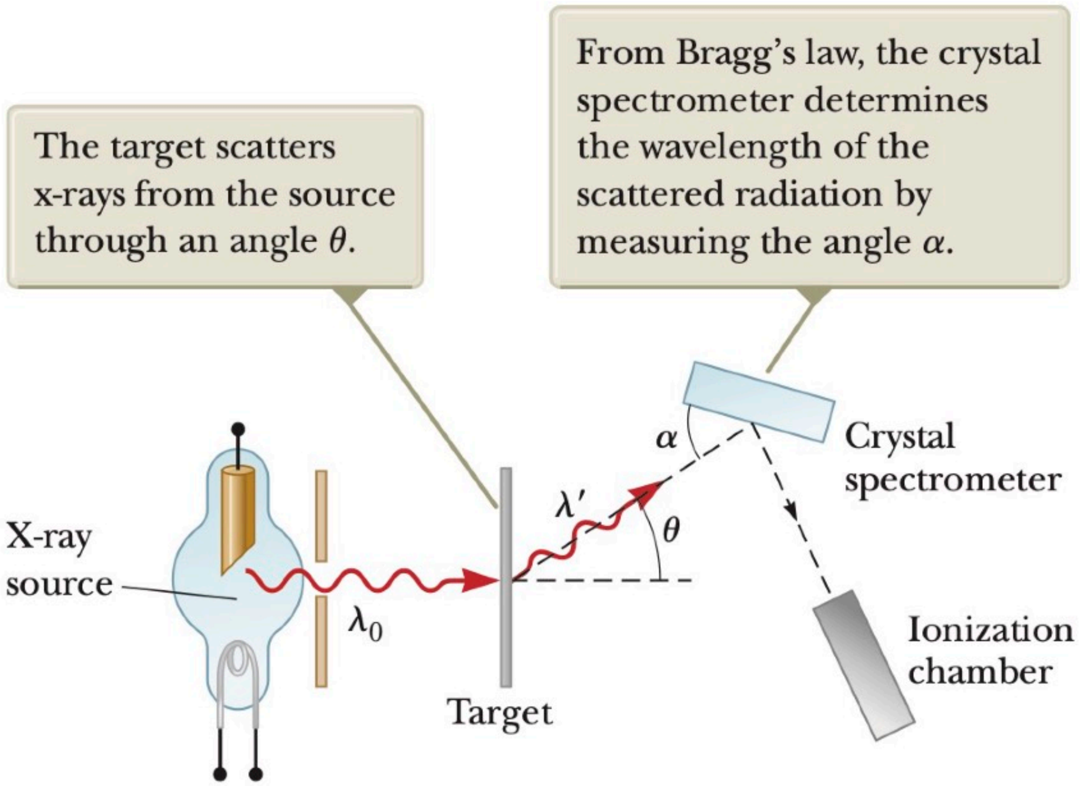
Arthur H. Compton observed the scattering of x-rays from electrons in a carbon target and found scattered x-rays with a longer wavelength than those incident upon the target.

Compton explained and modeled the data by assuming a particle (photon) nature for light and applying conservation of energy and conservation of momentum to the collision between the photon and the electron. The scattered photon has lower energy and therefore a longer wavelength according to the Planck relationship.

The Compton experiment gave clear and independent evidence of particle-like behavior.



$$\boxed{\lambda' - \lambda_0 = \frac{h}{m_e c}(1 - \cos\theta)}$$



The target scatters x-rays from the source through an angle θ.

From Bragg's law, the crystal spectrometer determines the wavelength of the scattered radiation by measuring the angle α.

The Compton effect

The wave properties of particles

Louis de Broglie

Reminder, in 1905, Einstein provided an explanation of the photoelectric effect. Einstein explained this by postulating that the electrons can receive energy from electromagnetic field only in discrete units (quanta or photons).

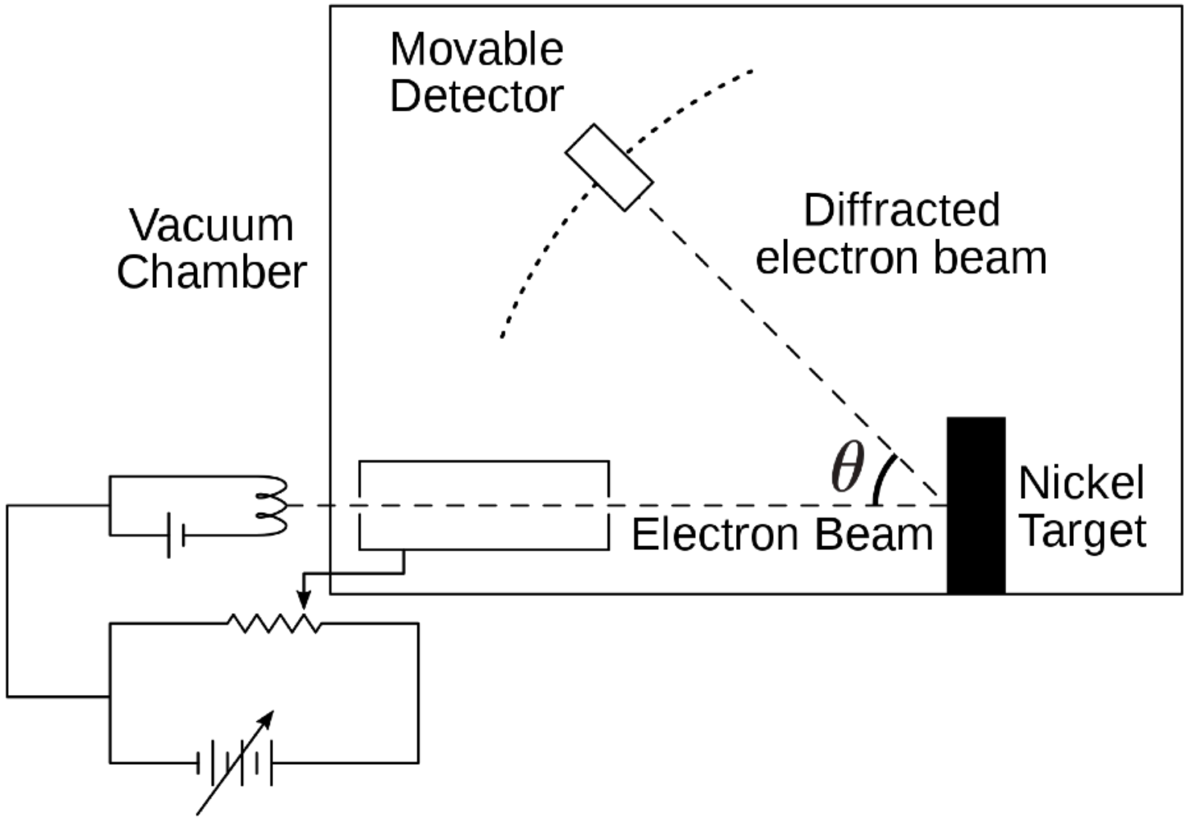
An amount of energy E that was related to the frequency f of the light by

Around 1923-1924, Louis de Broglie (in his Ph.D. thesis, Sorbonne) postulated that because photons have both wave and particle characteristics, perhaps all forms of matter have both properties. He proposed

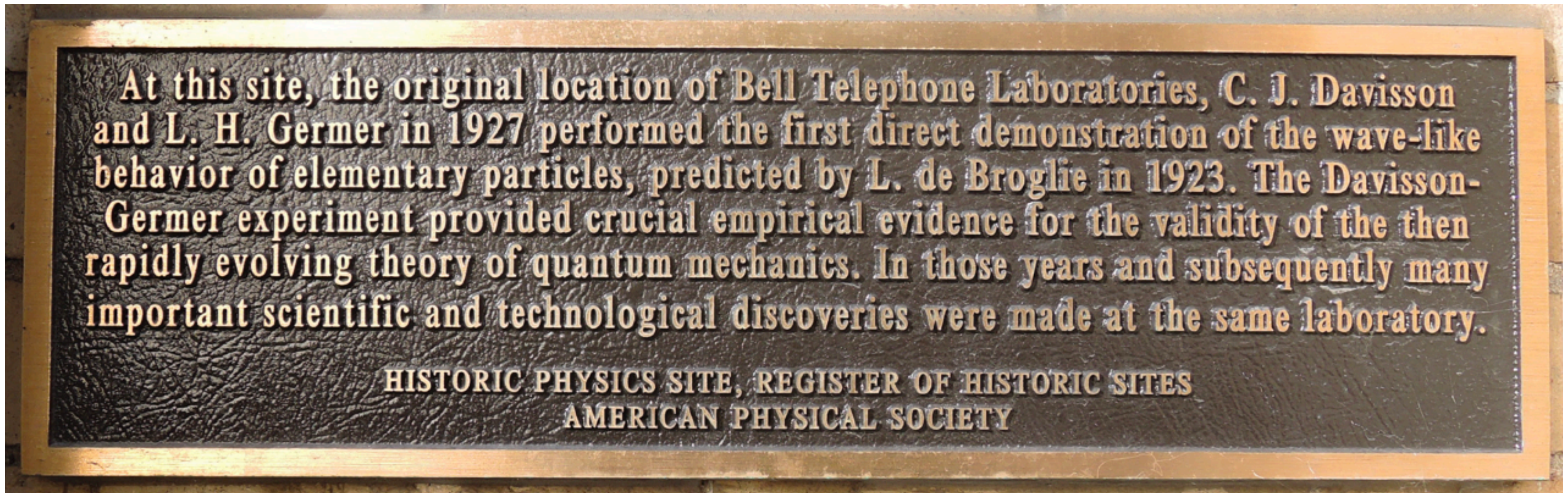
This can be considered to be a generalization of Einstein's equation. Why?

Davisson–Germer experiment

Davisson and Germer designed and built an apparatus for the purpose of measuring the energies of electrons scattered from a metal surface.



Davisson (left) holds a vacuum tube with Germer (right).



At this site, the original location of Bell Telephone Laboratories, C. J. Davisson and L. H. Germer in 1927 performed the first direct demonstration of the wave-like behavior of elementary particles, predicted by L. de Broglie in 1923. The Davisson-Germer experiment provided crucial empirical evidence for the validity of the then rapidly evolving theory of quantum mechanics. In those years and subsequently many important scientific and technological discoveries were made at the same laboratory.

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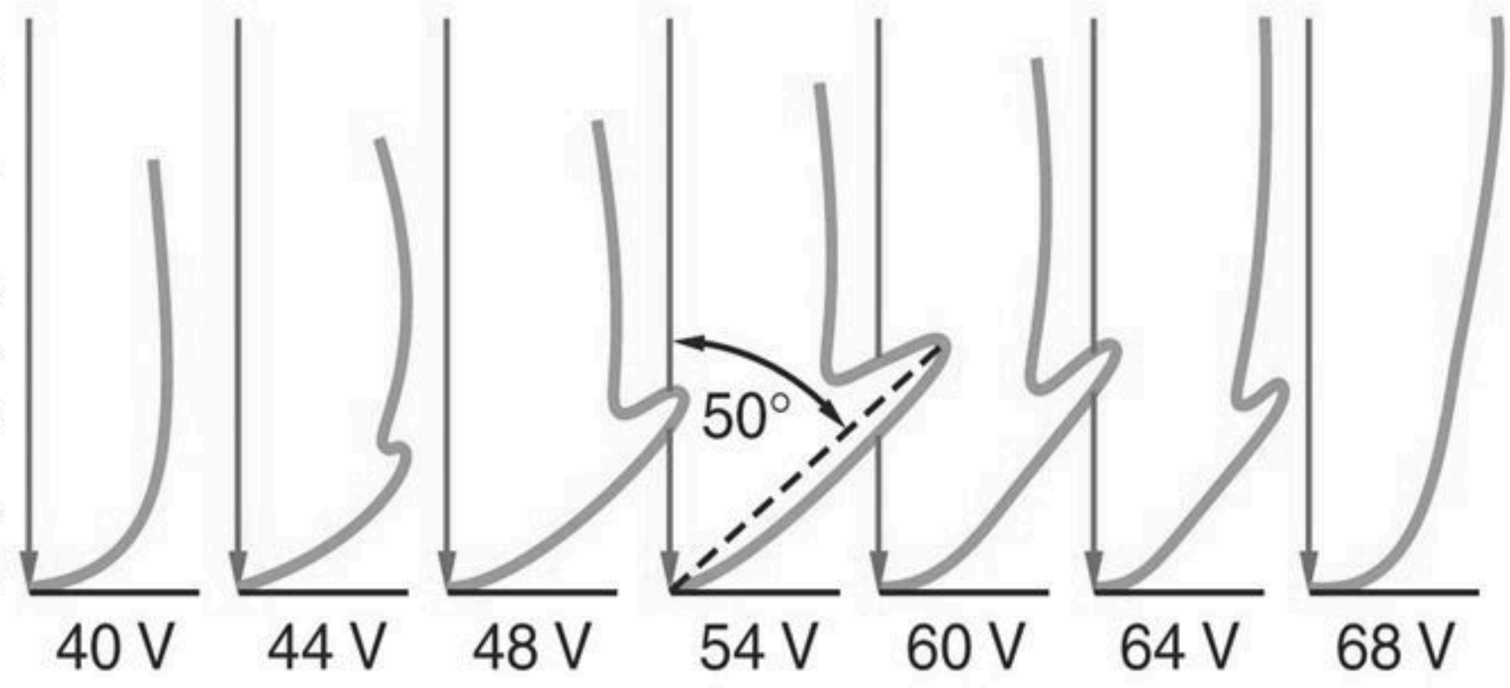
Davisson–Germer experiment



It was a great surprise to them to find that at certain angles there was a peak in the intensity of the scattered electron beam. This peak indicated wave behavior for the electrons, and could be interpreted by the Bragg law to give values for the lattice spacing in the nickel crystal.

de Broglie

Bragg