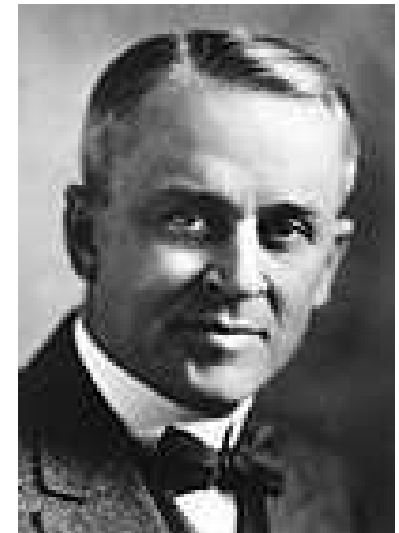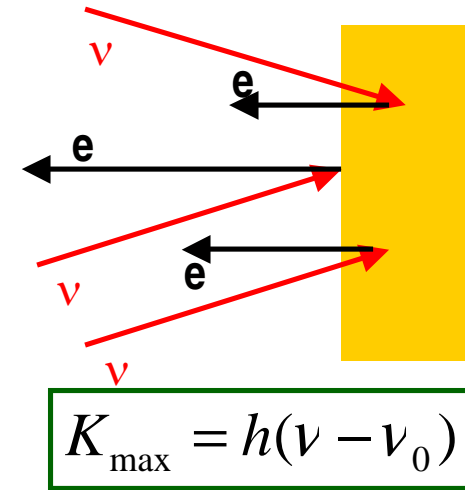# Further evidence for photons

The photoelectric effect:

1) The maximum electron energy depends only on ν and increases linearly with ν: **$E_{max} = h\nu - W$** (Millikan 1916)

2) There is a minimum ν independent of intensity. It is the Work function **W** divided by **h**.

3) The first emission happens faster than a wave would deposit energy (Lawrence and Beams 1928)

4) Different metals lead to the same value for **h**

$$K_{max} = h(\nu - \nu_0)$$

Robert A. Millikan
(1868-1953, USA)
1923 Nobel prize

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Further evidence for photons

Bremsstrahlung

The maximum emitted frequency depends only on the electron energy, not on the e-beam intensity. Highest frequency is linear in electron energy.

Typical electron energies are keV, and the work function of a few eV can therefore be neglected. (Duane and Hunt 1915)
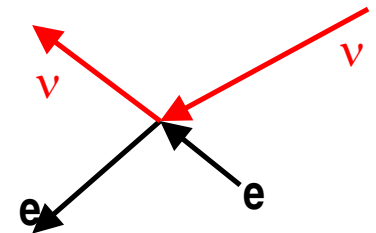
$$\nu_{max} = \frac{K_e}{h}$$
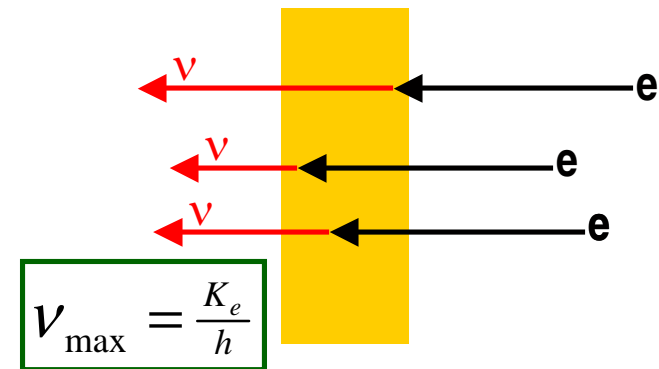
The Compton effect:

Scattering of light with free electrons follows the formulas of classical scattering of free particles when one assumes an energy **E=hν** and momentum **p=E/c=h/λ** for the photons. (Compton 1919-1923)

Artur H. Compton, 1892-1962
Nobel Prize in Physics, 1927

1) Simple models of the atom

Many **properties of macroscopic** bodies can not be understood without insight into the microscopic makeup of these bodies: Elasticity, heat conductivity, transparency, …

Emission spectra of vapors. The pattern of emission lines is characteristic of each chemical element.

λ ← **700 nm**   Balmer series of Hydrogen: **400 nm**

430 THz or 1.8 eV/h   **750 THz or 3.1 eV/h** ν
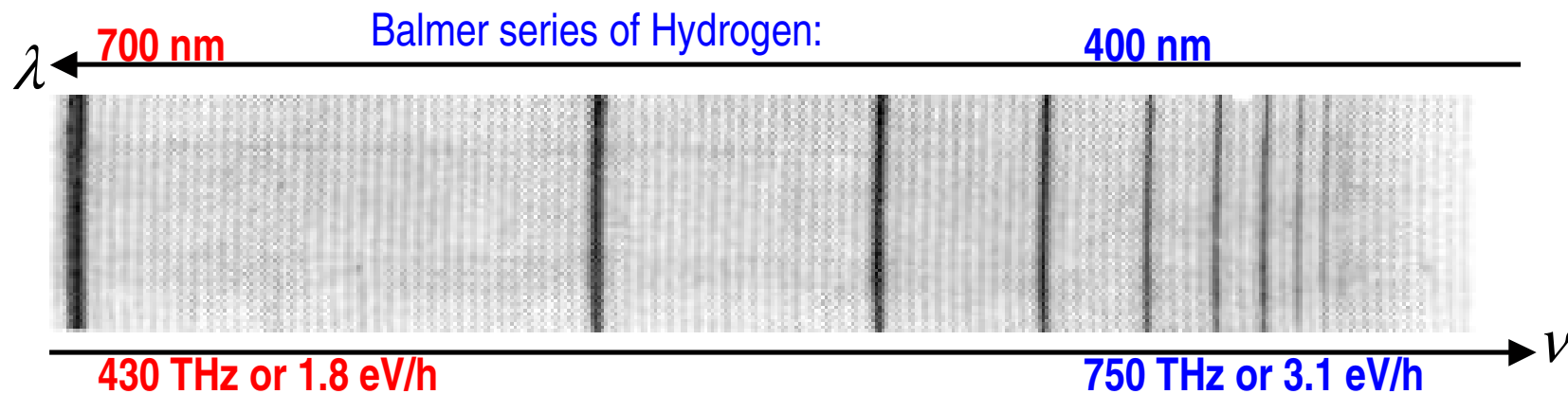
Balmer, 1885: $\nu_n \propto \left(\frac{1}{4} - \frac{1}{n^2}\right)$

"Strive to think a lot, not to know a lot"

What are the properties of the small particles that make up matter.

Democrit
460-371 BC
Early atomic theory

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The electrical structure of matter

1834: Michael Faraday showed that the amount of a gas liberated in electrolysis is proportional to the consumed electric charge.The ratio of the masses of different gases that are liberated by a given charge is the same as the mass ratio with which these gases usually react:

Example: $H_2O \rightarrow 2H^+ + O^{2-}$
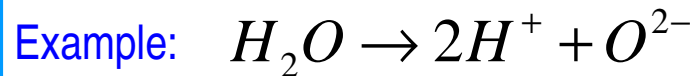
1897: Joseph Thomson showed that cathode rays were made of particles since they followed the

classical Lorentz force $m\vec{a} = e(\vec{E} + \vec{v} \times \vec{B})$ in an electromagnetic field.

Joseph J. Thomson
(1856-1840, UK)
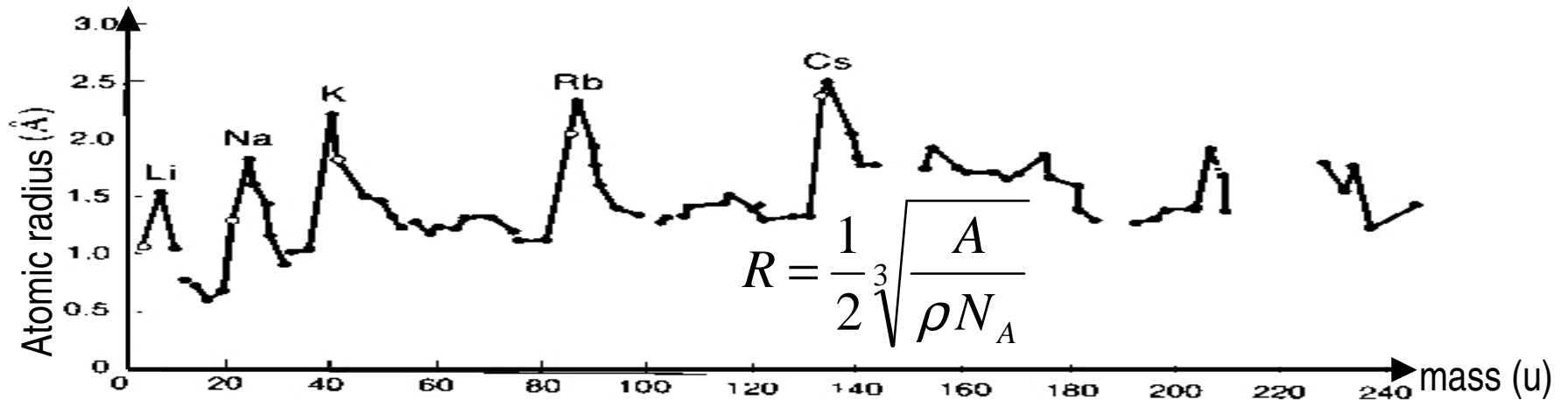1906 Nobel Prize
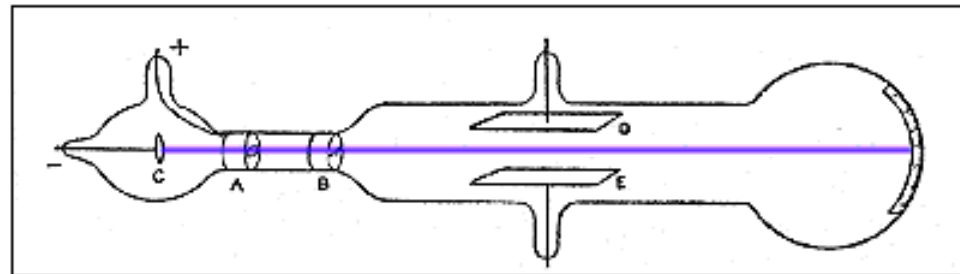
"The atom is not indivisible"

Michael Faraday
(1791-1867, UK)

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The elementary charge

After electrolytic mass per consumed charge was measured, the knowledge of the charge per ion would lead to the **number of atoms in a mol** as well as the **mass and size of atoms** .
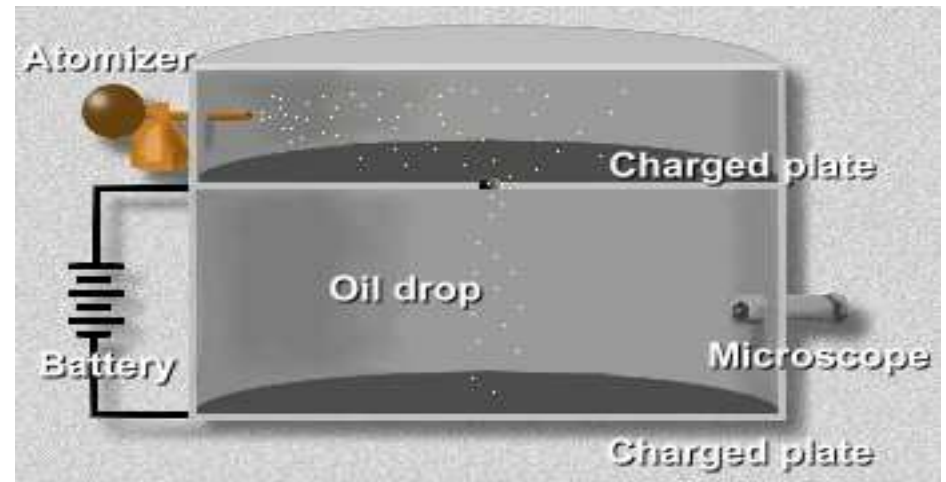

$$R = \frac{1}{2}\sqrt[3]{\frac{A}{\rho N_A}}$$

Atomic radii. There is relatively little variation around 1.5A, with larger radii for alkali atoms.

Millikan experiment

1909 - 1913

$$e = 1.6022 \cdot 10^{-19}\,\mathrm{C}$$

$$N_A = \frac{1\mathrm{F}}{e} = 6.022 \cdot 10^{23}$$

$$V_a[\tfrac{m^3}{atom}] = (2R)^3 = \frac{A\frac{g}{mol}}{\rho[\frac{g}{m^3}]N_A[\frac{atoms}{mol}]}$$

Georg.Hoffstaetter@Cornell.edu