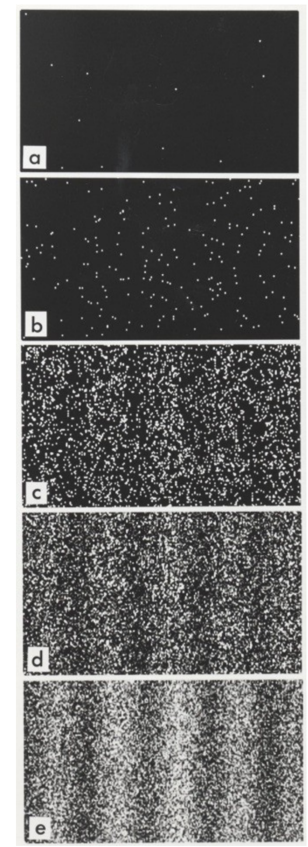
(Re)Visão de Física Moderna

- Experimentos e problemas históricos:
  - Dualidade onda-partícula.
  - Espectros atômicos.



A dualidade onda-partícula

Louis de Broglie (1892-1987)
Nobel de Física 1929

A hipótese de de Broglie – ondas de matéria:

$$\lambda = \frac{h}{p} \qquad \nu = \frac{E}{h}$$

$\vec{p}$ = momento linear da partícula

E = energia total da partícula

Partícula livre:

$$K = \frac{p^2}{2m} \Rightarrow \lambda = \frac{h}{\sqrt{2mK}}$$

K = energia cinética da partícula

Exemplos: Calcular o comprimento de onda associado a:

1) Um elétron acelerado por uma diferença de potencial de 100 V.

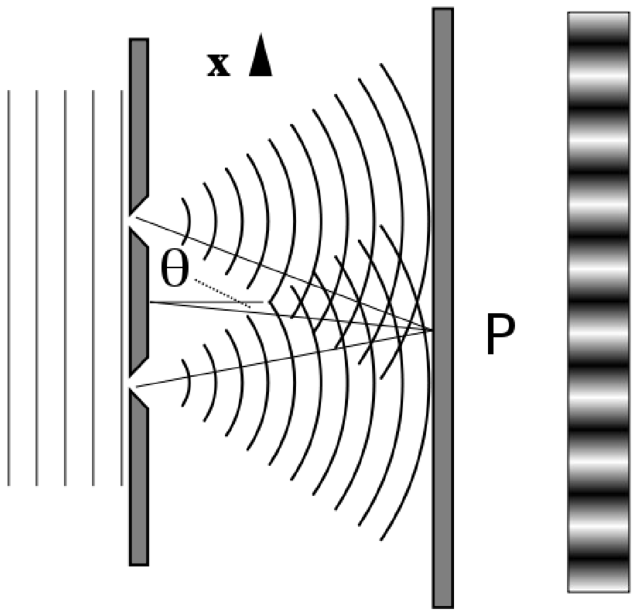
2) Uma bolinha de gude com massa 60 g e velocidade 10 m/s.

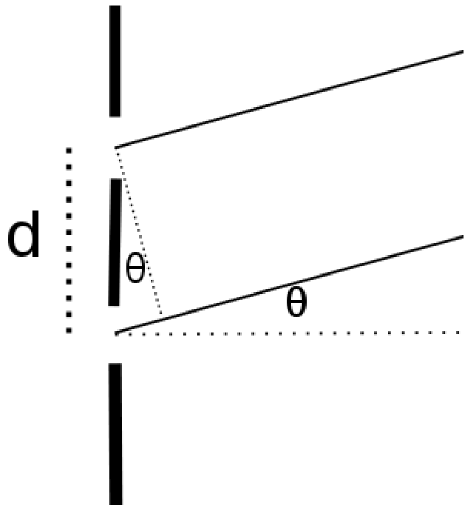
$$\lambda_{elétron} = 0{,}12 \text{ nm}$$

$$\lambda_{bolinha} = 1{,}1\times 10^{-33} \text{ m}$$

Difração e interferência de partículas

Experimentos de difração em fenda dupla (experimento de Young):





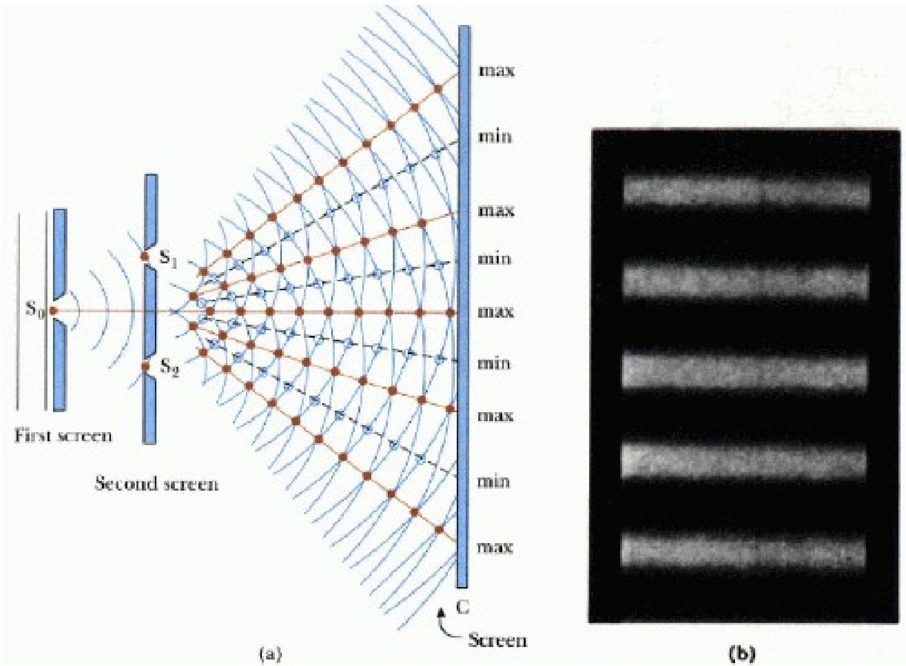
Máximos de interferência: $$d\,\mathrm{sen}\theta = m\lambda$$

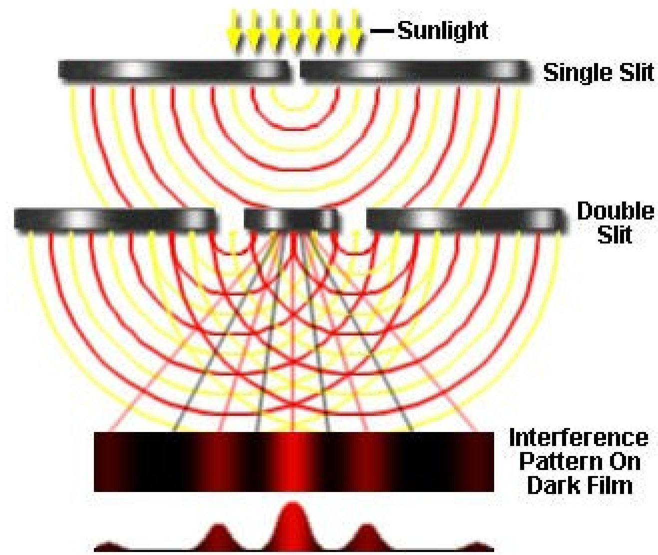
$m = 0, 1, 2, 3, \ldots$

http://en.wikipedia.org/wiki/Double-slit_experiment

Difração e interferência de partículas

Experimentos de difração em fenda dupla (experimento de Young):



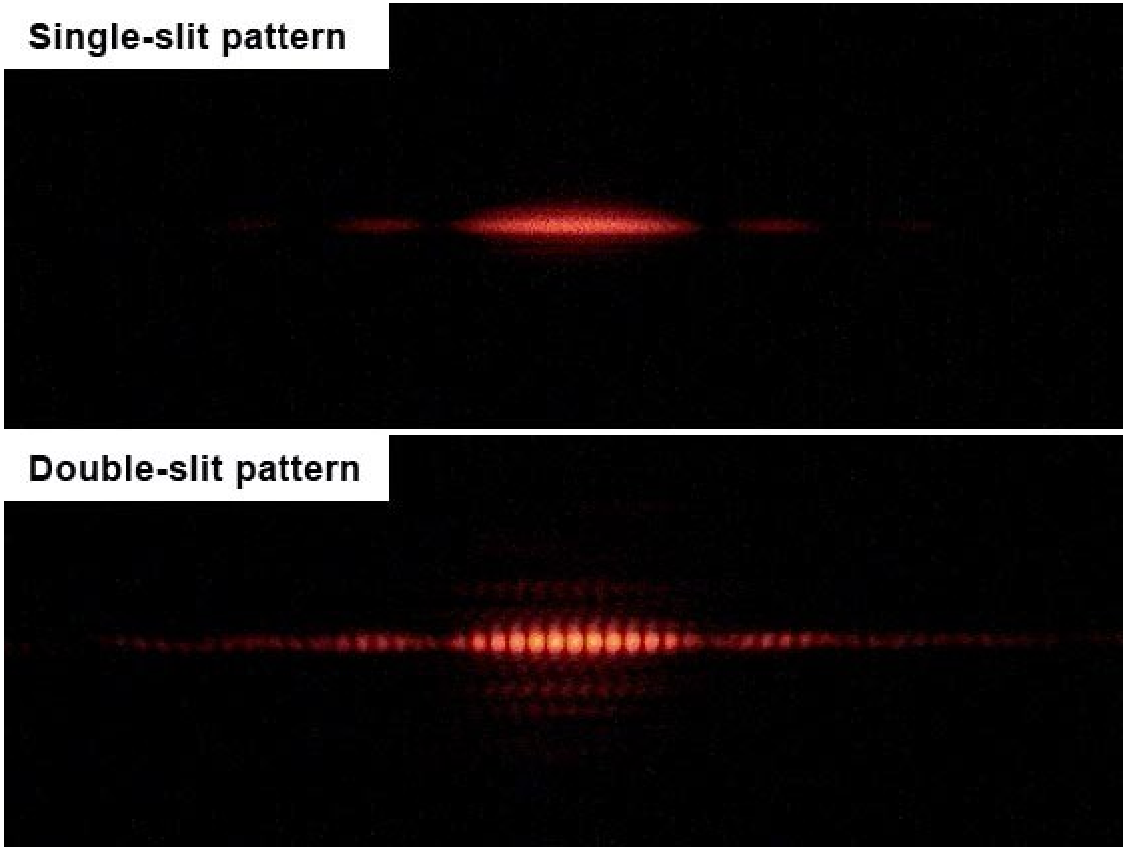


http://psi.phys.wits.ac.za/teaching/Connell/phys284/2005/lecture-02/lecture_02/node3.html

http://www.chem1.com/acad/webtext/atoms/atpt-2.html

Difração e interferência de partículas

Experimentos de difração em fenda dupla (experimento de Young):



http://en.wikipedia.org/wiki/Double-slit_experiment

Difração e interferência de partículas

O experimento de Davisson-Germer:

Second Series *December, 1927* *Vol. 30, No. 6*

THE

PHYSICAL REVIEW

DIFFRACTION OF ELECTRONS BY A CRYSTAL OF NICKEL

BY C. DAVISSON AND L. H. GERMER

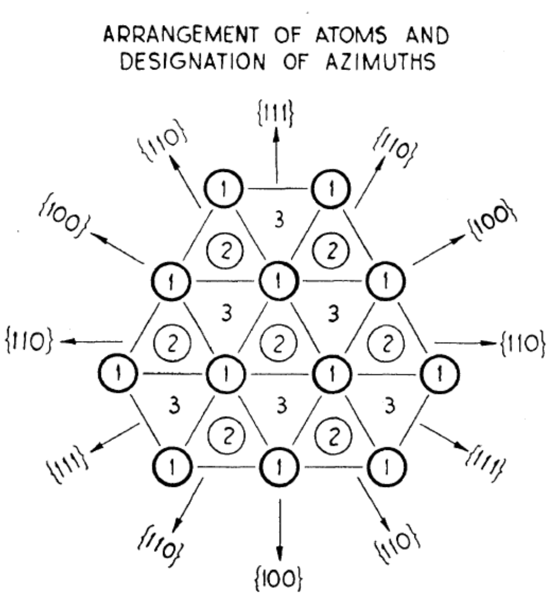
THE investigation reported in this paper was begun as the result of an accident which occurred in this laboratory in April 1925. At that time we were continuing an investigation, first reported in 1921,[1] of the distribution-in-angle of electrons scattered by a target of ordinary (polycrystalline) nickel. During the course of this work a liquid-air bottle exploded at a time when the target was at a high temperature; the experimental tube was broken, and the target heavily oxidized by the inrushing air. The oxide was eventually reduced and a layer of the target removed by vaporization, but only after prolonged heating at various high temperatures in hydrogen and in vacuum.

Davisson & Germer, *Phys. Rev.* 1927;30:705-740

Clinton Davisson (1881-1958) – *Nobel de Física 1937*
Lester Germer (1896-1971)

Difração e interferência de partículas

O experimento de Davisson-Germer:



Alvo: Cristal de Ni (fcc)

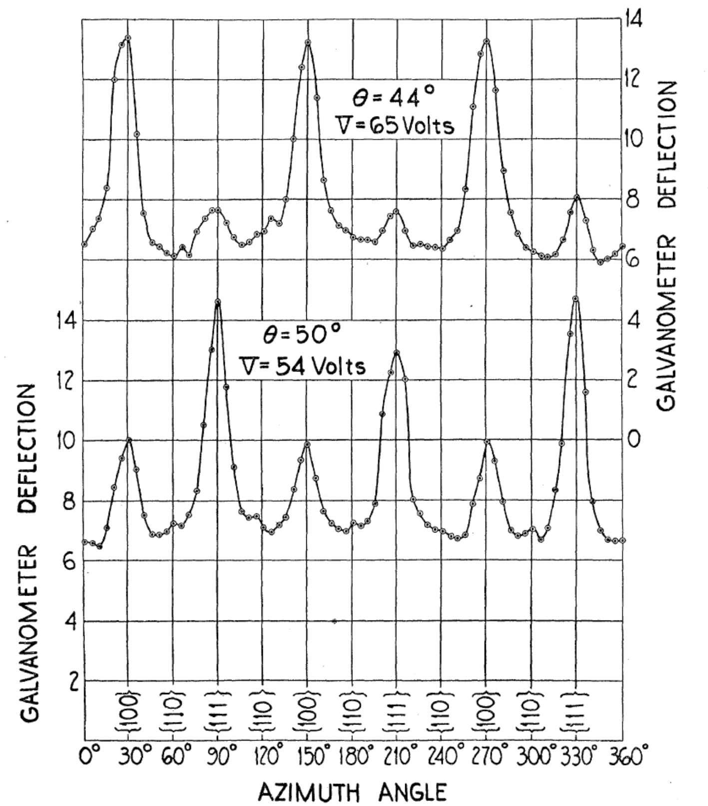


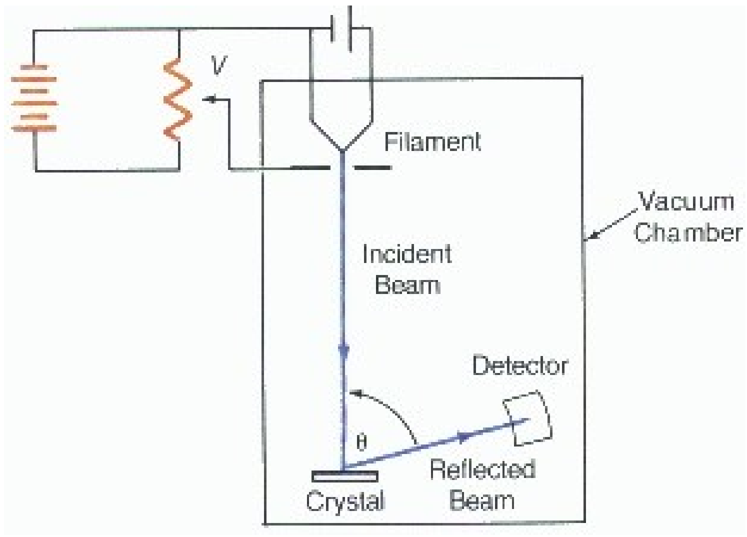
Fig. 11. Azimuth scattering curves through the "54-volt" electron beam and through the "65-volt" electron beam.

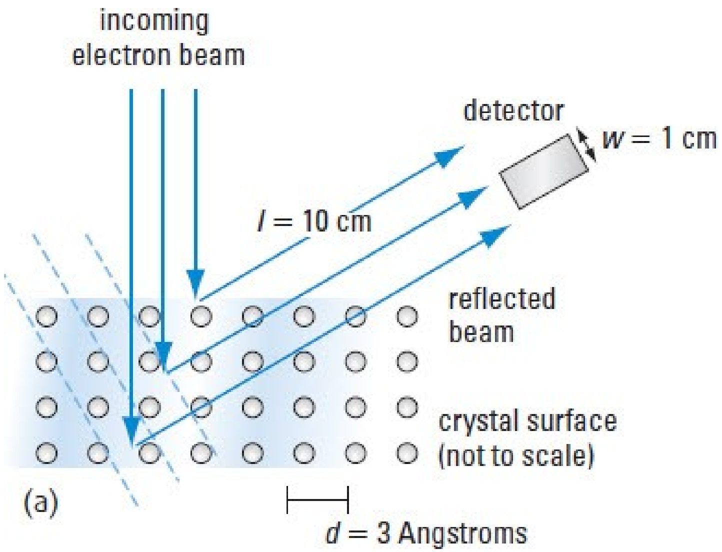
Resultados para feixes com diferentes comprimentos de onda

Davisson & Germer, *Phys. Rev.* 1927;30:705-740

Difração e interferência de partículas

O experimento de Davisson-Germer:

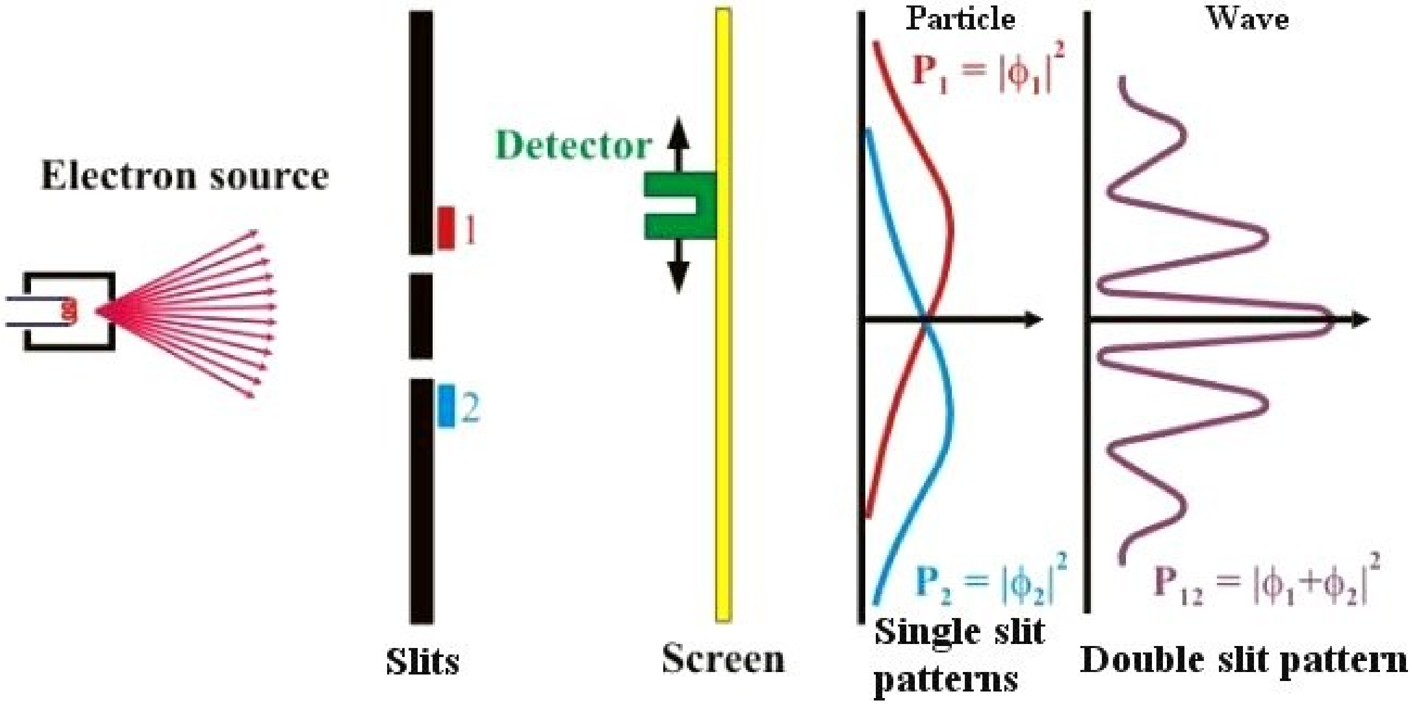




http://mail.rdcrd.ab.ca/~smolesky/FOV1-000293AF/5Matter/FOV1-0002A9D2/FOV1-0002A9E4/?7-31&Show=0&Filter=0&DisplayFormat=0

Difração e interferência de partículas

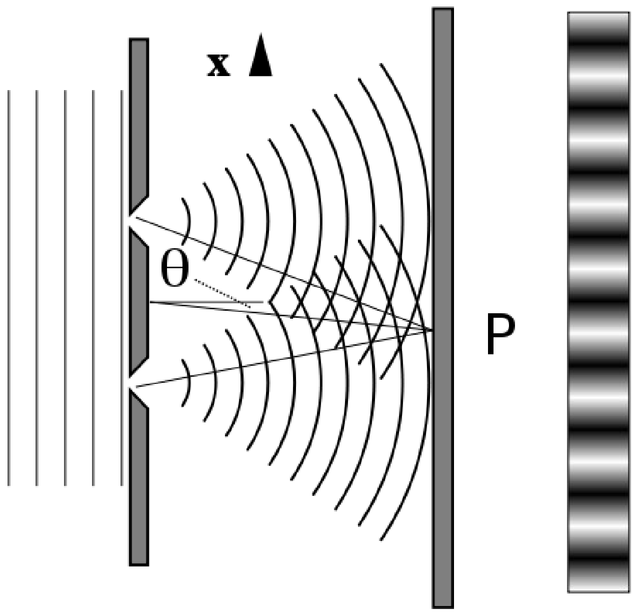
Experimentos de difração com elétrons:

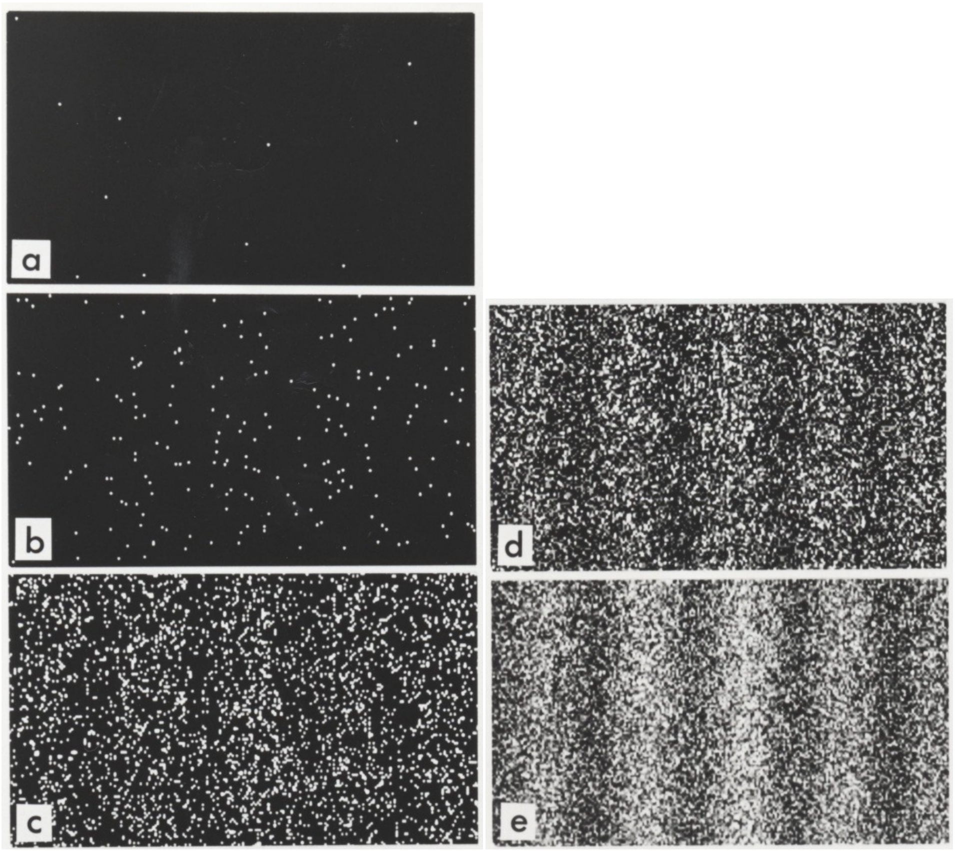


http://universe-review.ca/F12-molecule.htm

Difração e interferência de partículas

Experimentos de difração com elétrons:





Formação do padrão de interferência ao longo do tempo de exposição

http://en.wikipedia.org/wiki/Double-slit_experiment

Difração e interferência de partículas

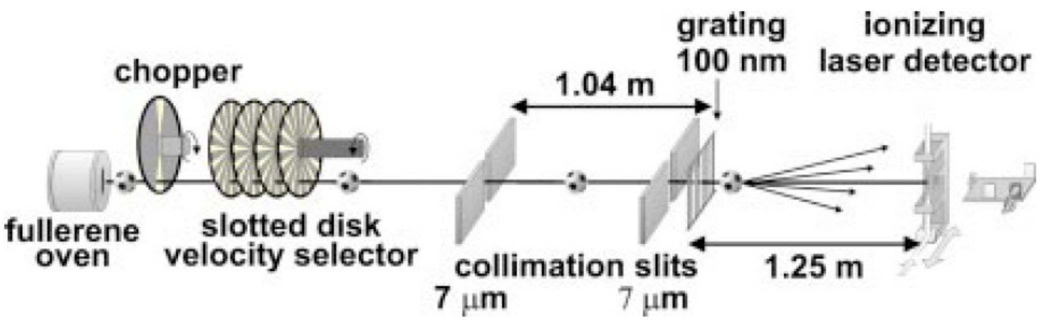
Experimentos de difração com moléculas:

Fig. 2. The fullerene molecule C_{60}, consisting of 60 carbon atoms arranged in a truncated icosahedral shape, is the smallest known natural soccer ball.

Fulereno – C_{60}

Diâmetro ~ 1 nm

λ ~ 2,8 pm



Zeilinger et al.. *Am. J. Phys.* 2003;71:319-325

Difração e interferência de partículas

Experimentos de difração com moléculas:

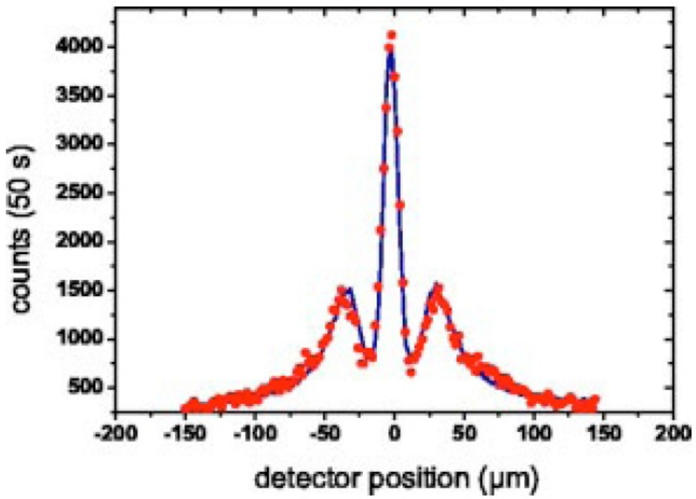


Fig. 6. Far-field diffraction of C_{60} using a thermal beam of $\overline{v}=200$ m/s with a velocity spread of $\Delta v/v\sim 60\%$. The absence of higher order interference fringes is due to the poor spectral coherence.

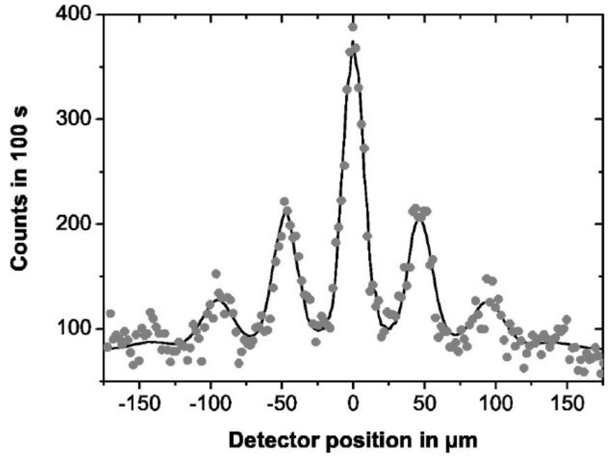


Fig. 7. Far-field diffraction of C_{60} using the slotted disk velocity selector. The mean velocity was $\overline{v}=117$ m/s, and the width was $\Delta v/v\sim 17\%$. Full circles represent the experimental data. The full line is a numerical model based on Kirchhoff–Fresnel diffraction theory. The van der Waals interaction between the molecule and the grating wall is taken into account in form of a reduced slit width. Grating defects (holes) additionally contribute to the zeroth order.

Zeilinger et al.. *Am. J. Phys.* 2003;71:319-325

Difração e interferência de partículas

Difração de elétrons e nêutrons:

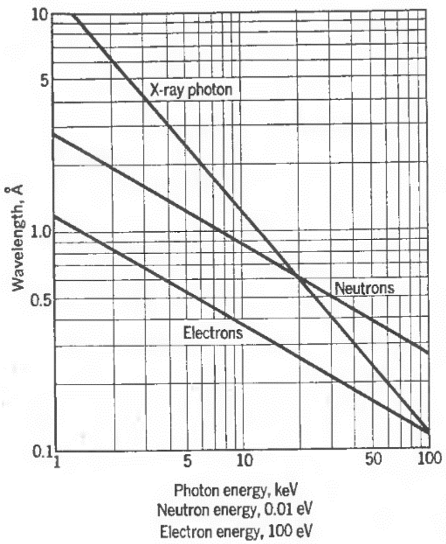


Figure 1 Wavelength versus particle energy, for photons, neutrons, and electrons.

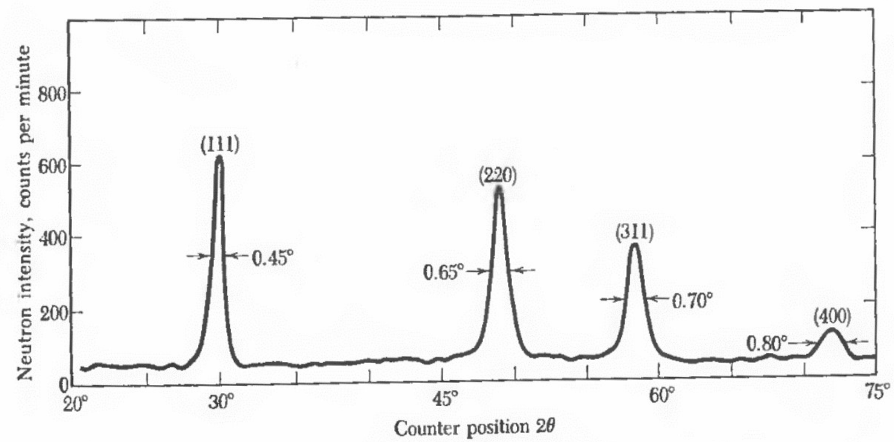
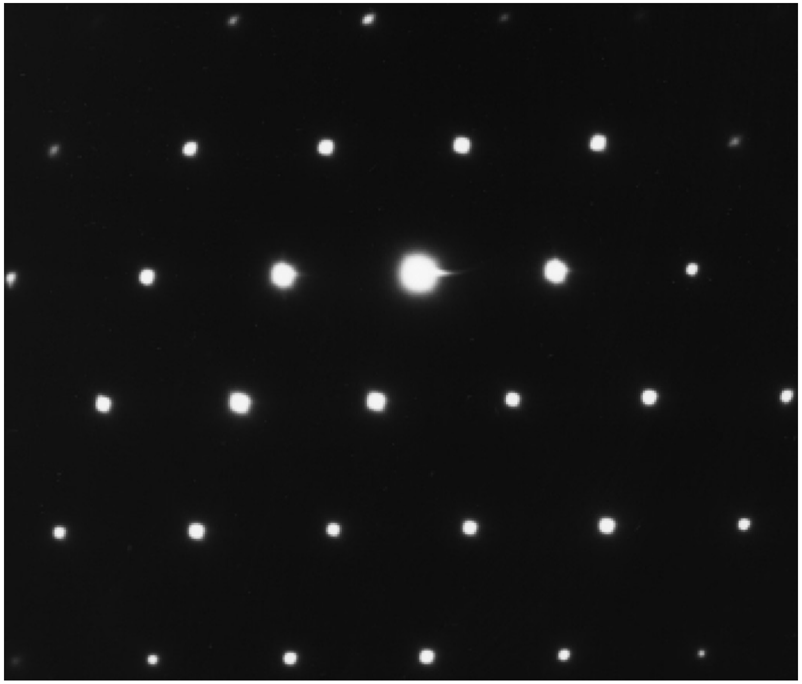


Figure 21 Neutron diffraction pattern for powdered diamond. (After G. Bacon.)

Introduction to Solid State Physics, Kittel, 1996.

Difração e interferência de partículas

Difração de elétrons e nêutrons:

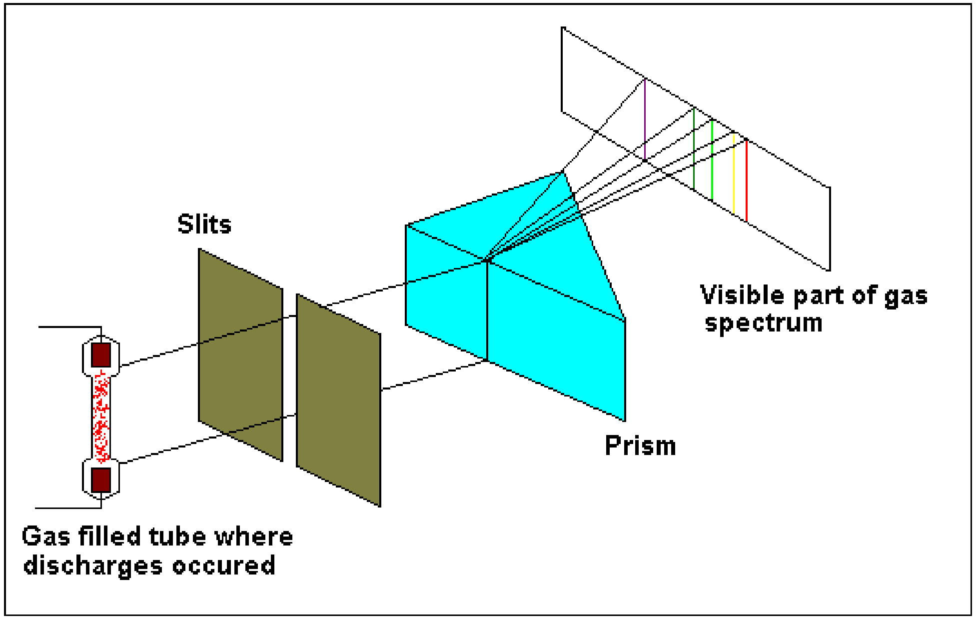


This photograph shows a diffraction pattern produced for a single crystal of gallium arsenide using a transmission electron microscope. The brightest spot near the center is produced by the incident electron beam, which is parallel to a $\langle 110 \rangle$ crystallographic direction. Each of the other white spots results from an electron beam that is diffracted by a specific set of crystallographic planes. (Photograph courtesy of Dr. Raghaw S. Rai, Motorola, Inc., Austin, Texas.)

Fundamentals of Materials Science and Engineering , Callister.

Espectros atômicos

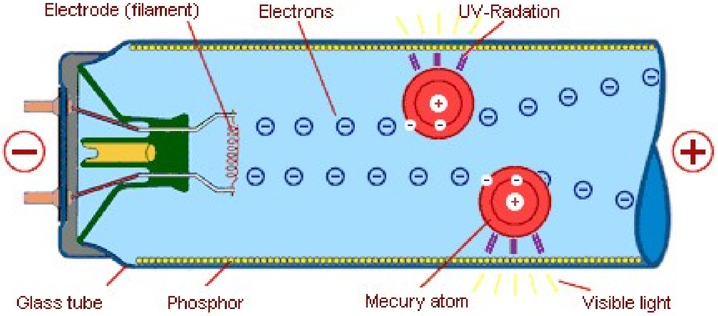
Espectros discretos (raias):



Discharges in the low - pressure gas filled tube are sources of light, which undergo refraction on a prism. We see the line spectrum of the gas.

http://library.thinkquest.org/28383/nowe_teksty/htmla/2_13a.html

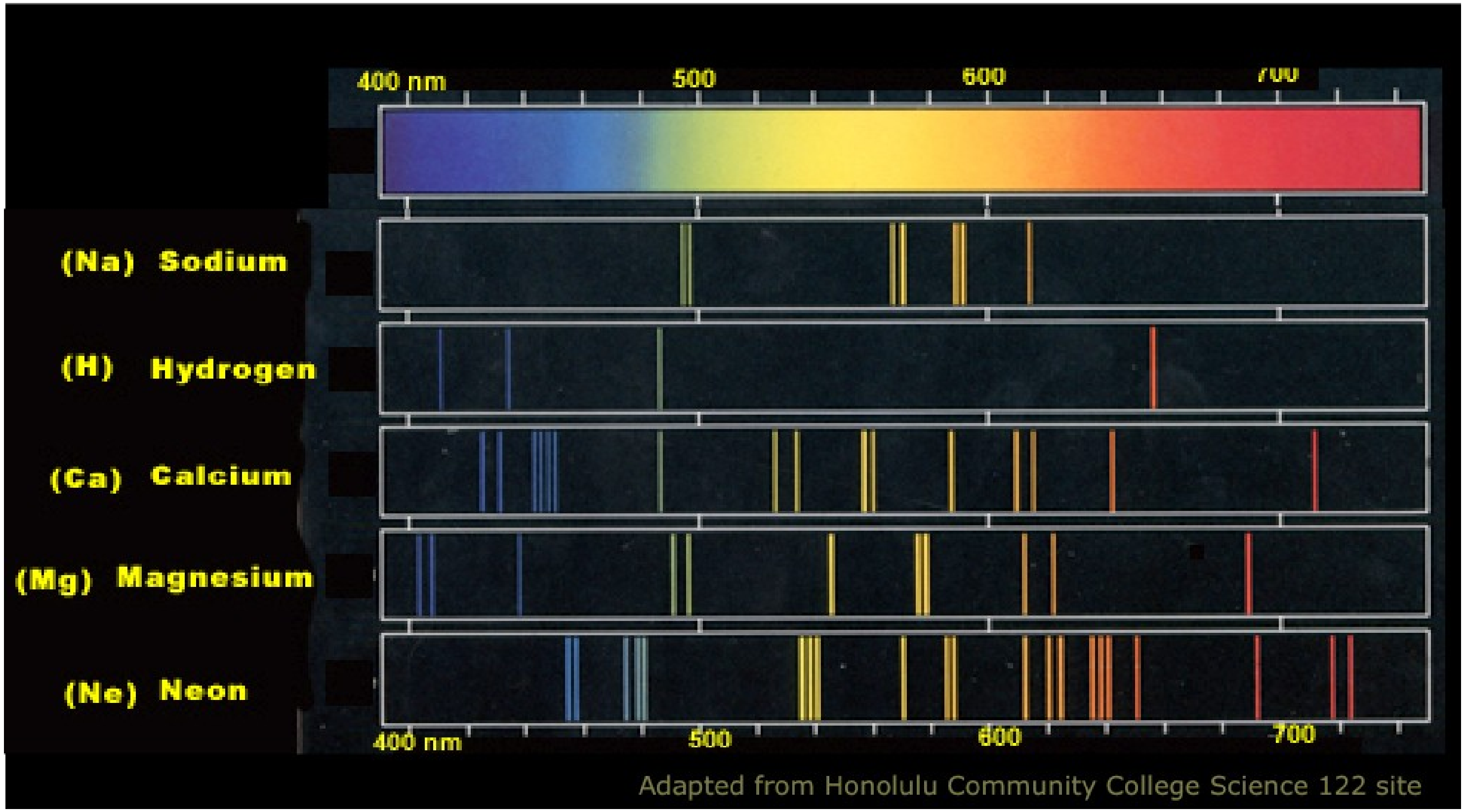
Lâmpada fluorescente:



http://www.osram.com/osram_com/Professionals/General_Lighting/Fluorescent_lamps/Technologies/Low-pressure_gas_discharge/index.html

Espectros atômicos

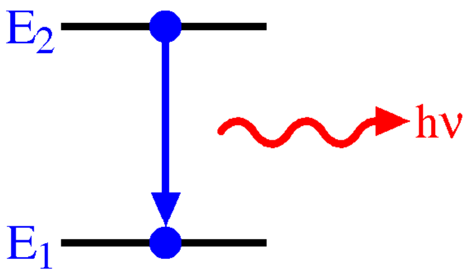
Espectros discretos (raias):



http://faculty.virginia.edu/consciousness/new_page_6.htm

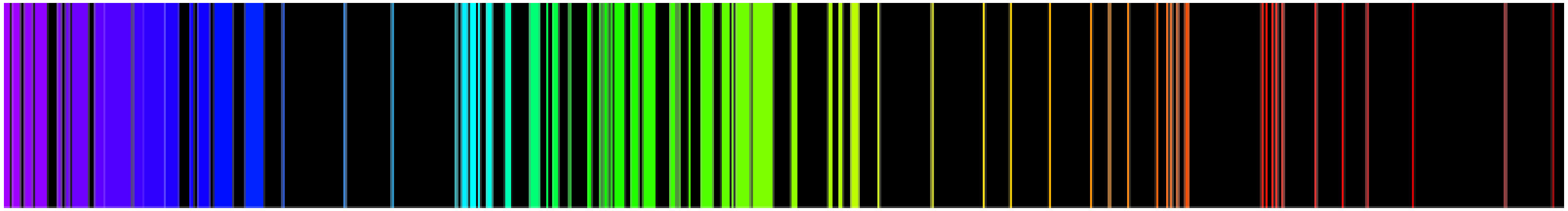
Espectros atômicos

Espectros discretos (raias):



Hidrogênio:

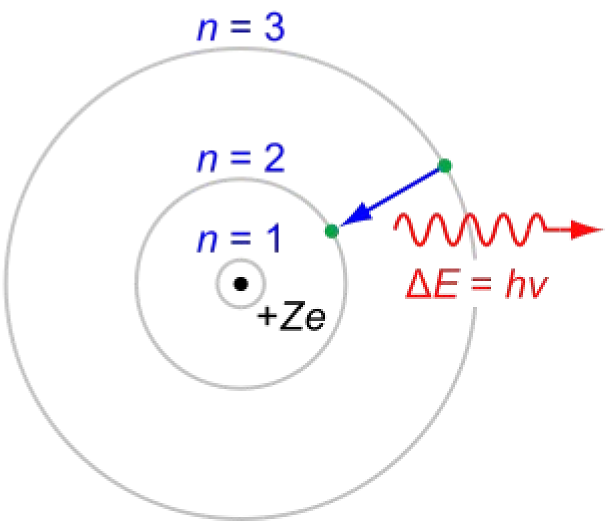
Ferro:



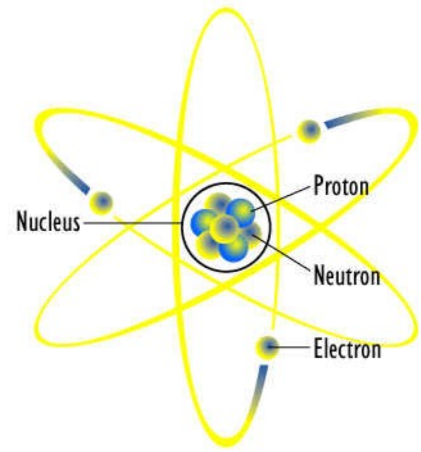
http://en.wikipedia.org/wiki/Emission_spectrum

Modelo de Bohr

Contribuições de Rutherford, Bohr, Sommerfeld, ...

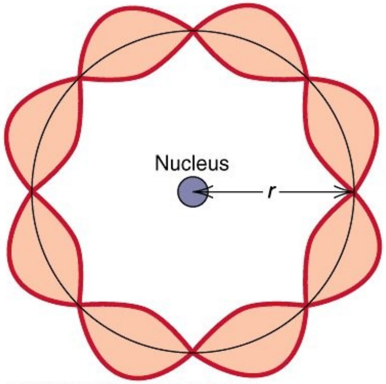


http://en.wikipedia.org/wiki/Bohr_model



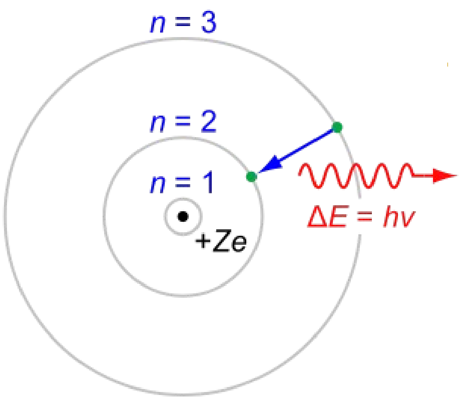
http://2011period5group2.wikispaces.com/Niels+Bohr

Niels Bohr (1885-1962)
Nobel de Física 1922



http://web.sbu.edu/chemistry/wier/electrons/debroglie.html

Modelo de Bohr



Átomo de Hidrogênio:

Energia:

$$E_n = -\frac{\mu e^4}{8h^2\epsilon_0^2}\frac{1}{n^2} \quad ; \quad n = 1, 2, 3, \ldots$$

$$\mu = \frac{m\,M}{m + M}$$

Momento angular:

$$L_z = m\frac{h}{2\pi} = m\hbar$$

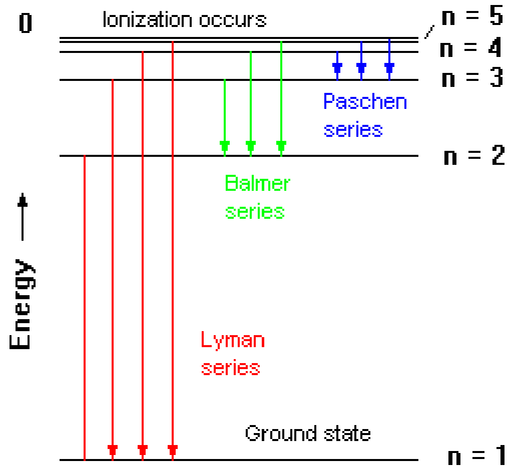
Frequência:

$$\bar{\nu} = -\frac{\mu e^4}{8h^2\epsilon_0^2}\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right) = R\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)$$

http://itl.chem.ufl.edu/4411L_f00/hatom/hatom.html

Modelo de Bohr

Cálculos das frequências no espectro de emissão do hidrogênio:



http://tannerm.com/Quick_atom/A4.htm

$$E_n = -\frac{13,6\ \mathrm{eV}}{n^2}$$

http://en.wikipedia.org/wiki/Emission_spectrum

Bibliografia:

- "*Materiais e Dispositivos Eletrônicos*", Sergio M. Rezende, 2ª edição. São Paulo: Livraria da Física, 2004.
- "*Ciência e Engenharia de Materiais – uma Introdução*", W. D. Callister Jr., 7a edição. Rio de Janeiro: LTC, 2008.
- "*Física Quântica. Átomos, Moléculas, Sólidos, Núcleos e Partículas*", R. Eisberg, R. Resnick, 6a ed., Rio de Janeiro: Editora Campus, 1979.
- "Quantum interference experiments with large molecules", O. Nairz, M. Arndt, A. Zeilinger. *Am. J. Phys.* 2003;71:319-325.