Instituto Federal de Educação, Ciência e Tecnologia - *Campus* São Paulo

Dualidade Onda-Partícula

e

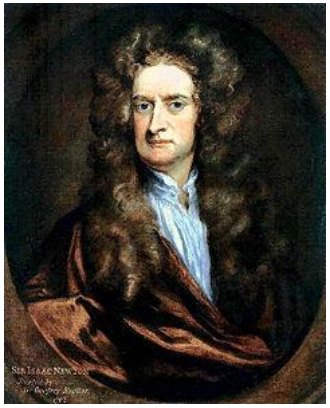
Princípio da Incerteza

3ª série FSC – Ensino Médio Integrado

André Cipoli

Breve cronologia dos modelos para a luz

- *Isaac Newton* (1640 - 1725): sucesso do modelo mecânico para explicar vários fenômenos.

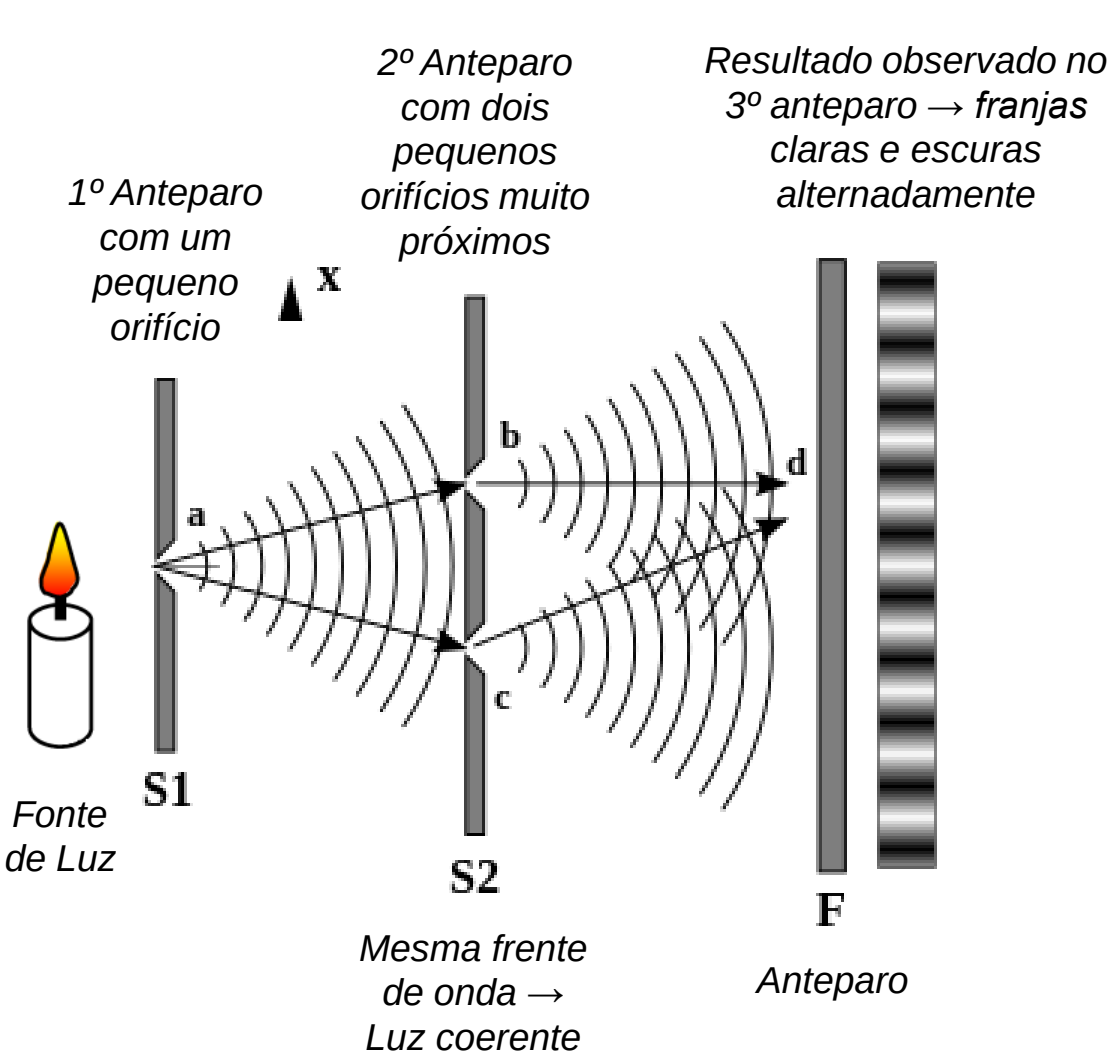


*Modelo **Corpuscular** da Luz*

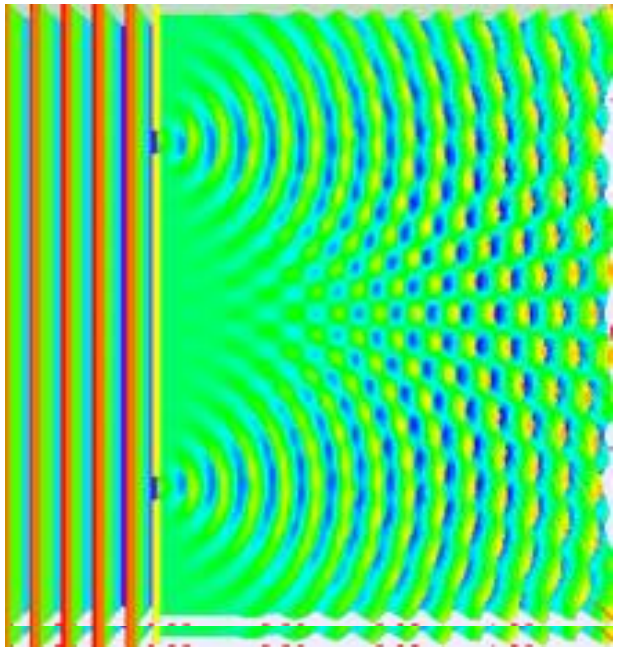
- *Christian Huygens* (1629 - 1695): fenômenos luminosos poderiam ser explicados mais facilmente considerando-os como ***ondas***.

*Modelo **Ondulatório** da Luz*

Cronologia - Experimento da dupla fenda



Thomas Young
1773 - 1829

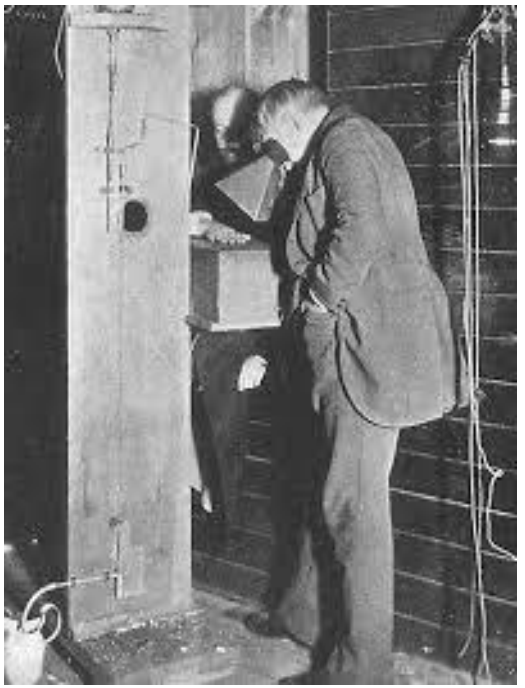


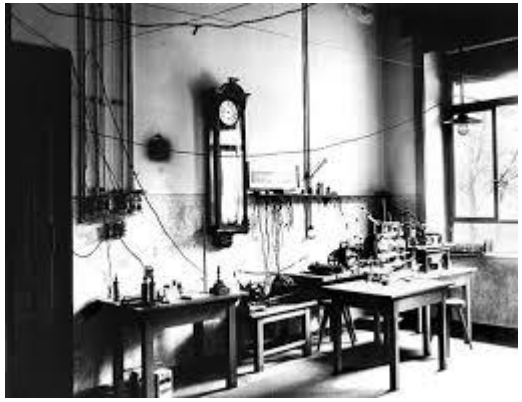
Natureza Ondulatória da Luz

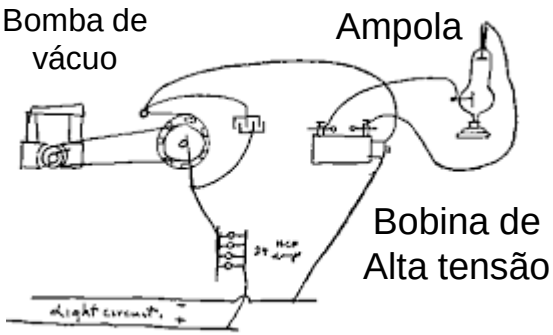
(1.801)

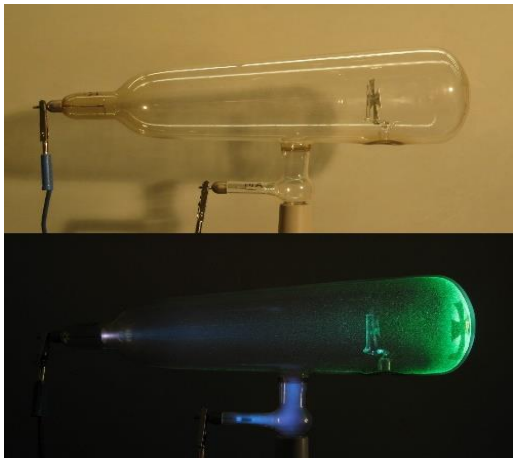
Cronologia - ***Descoberta dos Raios X*** - ***08/11/1895***

Wilhelm W. Roentgen
1845 - 1923
Nobel de ***1.901***





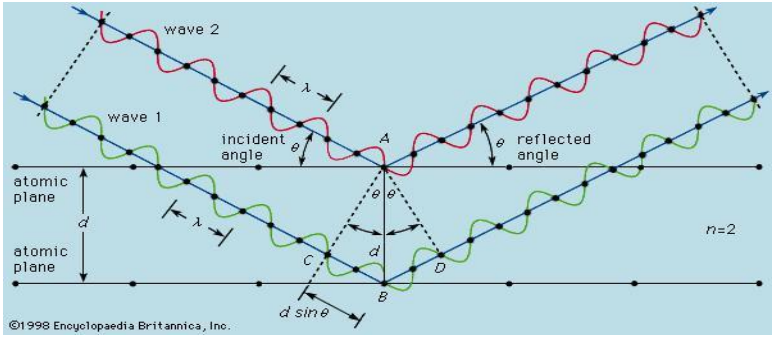




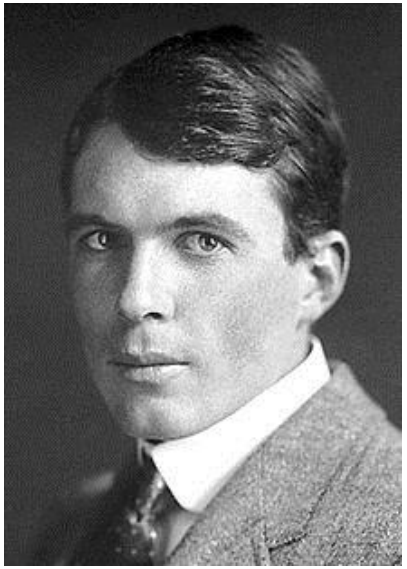
Cronologia

Cristalografia de Raios X

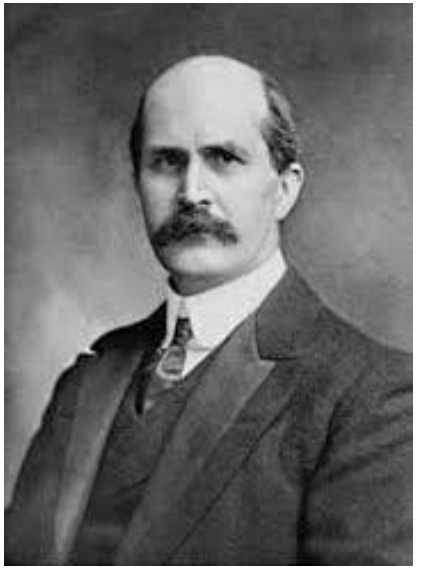
1912 - 1913



- *Análise da estrutura de cristais*
- *Parâmetros de rede cristalina*
- *Composição química*



William L. Bragg
1890 - 1971
Nobel de ***1.915***



Lawrence H. Bragg
1862 - 1942
Nobel de ***1.915***

$$n.\lambda = 2.d.sen\theta$$

n é inteiro positivo

(Interferência Construtiva)

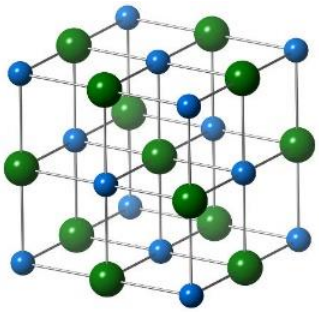
Padrão de difração de Raios X do NaCl

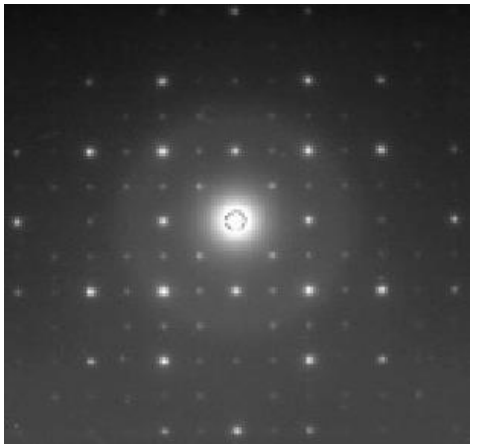
$d = 0{,}91 \times 10^{-10}\ m;$

$n = 1; \quad \theta = 65^{o}$

$\lambda = 2 \times 0{,}91 \times 10^{-10} \times \sin 65^{o} =$

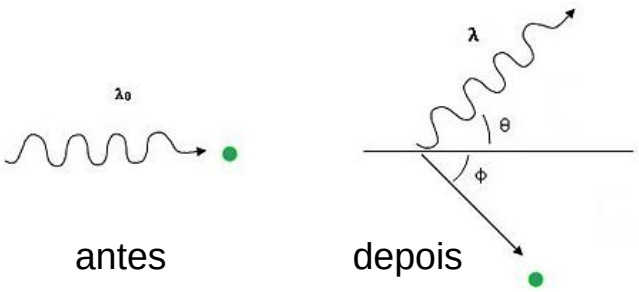
$1{,}65\ Å$





• em ***1.916***, Einstein demonstra que os fótons possuem momento linear, uma característica de matéria em movimento.

$$p = \frac{hf}{c} = \frac{h}{\lambda}$$



Albert Einstein
1879 - 1955
Nobel de ***1.921***

• em ***1.924***, de Broglie anuncia que os elétrons apresentam características tanto ondulatórias como corpusculares, comportando-se de um ou outro modo, dependendo do experimento específico.

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

Relações de ***de Broglie***

$$\lambda = \frac{h}{p} = \frac{6{,}62 \times 10^{-34}}{9{,}11 \times 10^{-31} \times 4{,}4 \times 10^{6}} = 1{,}65\ \text{Å}$$

$$\phi_{átomo} \approx 10^{-10} m$$

$$\phi_{núcleo} \approx 10^{-14} m$$

Louis V.P.R. *de Broglie*
1892 - 1987
Nobel de ***1.929***

Comprovação Experimental

Joseph John Thomson
1856 - 1940
Nobel de ***1.906***

George Paget Thomson
1892 - 1975
Nobel de ***1.937***

Clinton J. Davisson
1881 - 1958
Nobel de ***1.937***

Lester H. Germer
1896 - 1971

JOSEPH J. THOMSON

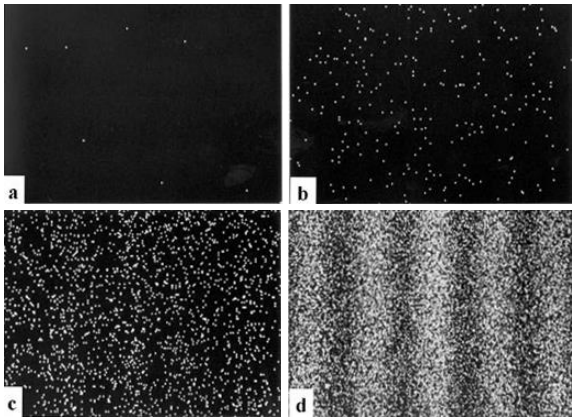
Carriers of negative electricity

Nobel Lecture, December 11, 1906

Introductory

In this lecture I wish to give an account of some investigations which have led to the conclusion that the carriers of negative electricity are bodies, which I have called corpuscles, having a mass very much smaller than that of the atom of any known element, and are of the same character from whatever source the negative electricity may be derived.

The first place in which corpuscles were detected was a highly exhausted tube through which an electric discharge was passing. When an electric discharge is sent through a highly exhausted tube, the sides of the tube glow with a vivid green phosphorescence. That this is due to something proceeding in straight lines from the cathode - the electrode where the negative electricity enters the tube - can be shown in the following way (the experiment is one made many years ago by Sir William Crookes): A Maltese cross made of thin mica is placed between the cathode and the walls of the tube. When the discharge is past, the green phosphorescence no longer extends all over the end of the tube, as it did when the cross was absent.



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THE

PHYSICAL REVIEW

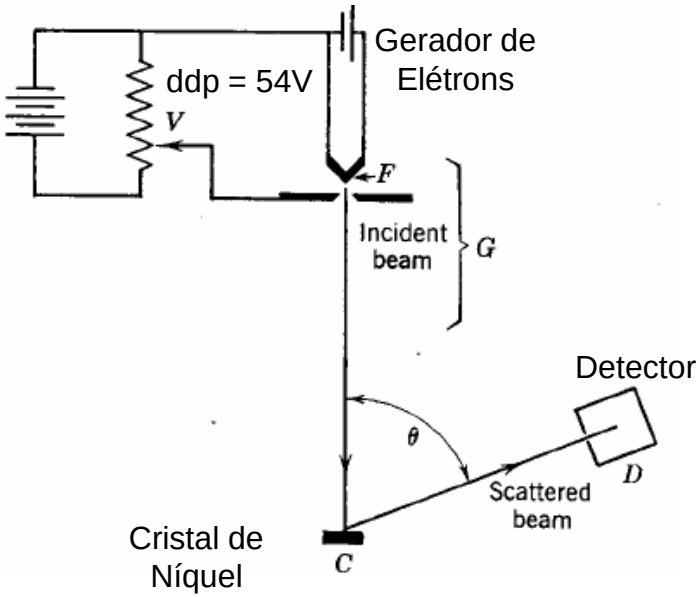
DIFFRACTION OF ELECTRONS BY A CRYSTAL OF NICKEL

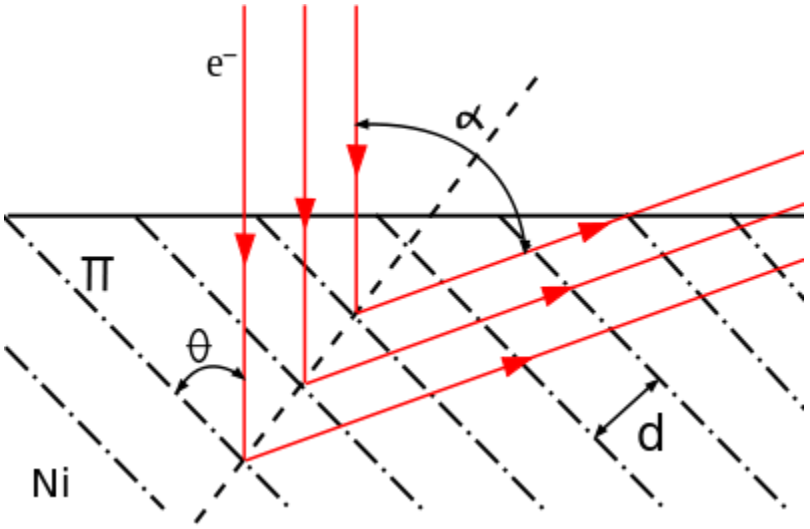
BY C. DAVISSON AND L. H. GERMER

ABSTRACT

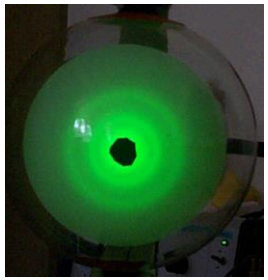
The intensity of scattering of a homogeneous beam of electrons of adjustable speed incident upon a single crystal of nickel has been measured as a function of direction. The crystal is cut parallel to a set of its {111}-planes and bombardment is at normal incidence. The distribution in latitude and azimuth has been determined for such scattered electrons as have lost little or none of their incident energy.

Dispositivo Experimental





$$n.\lambda = 2.d.sen\theta$$

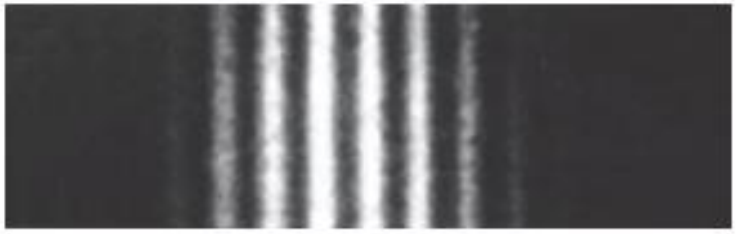


Difração de Elétrons
Tel 2555

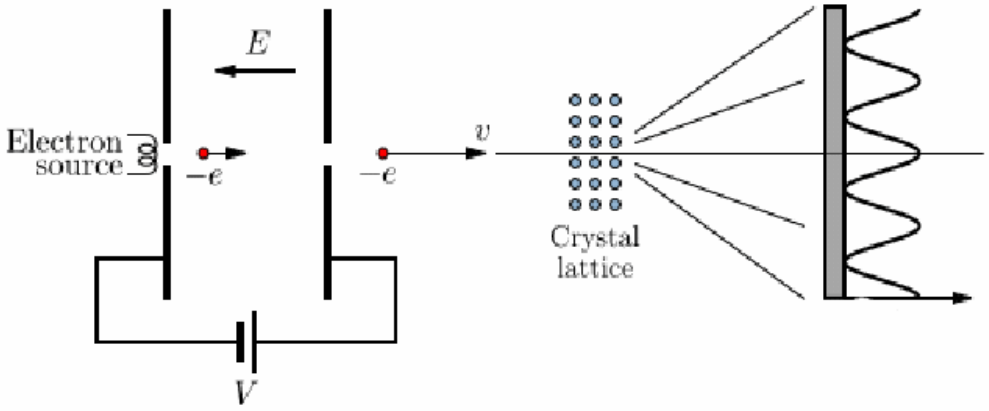
n é inteiro positivo

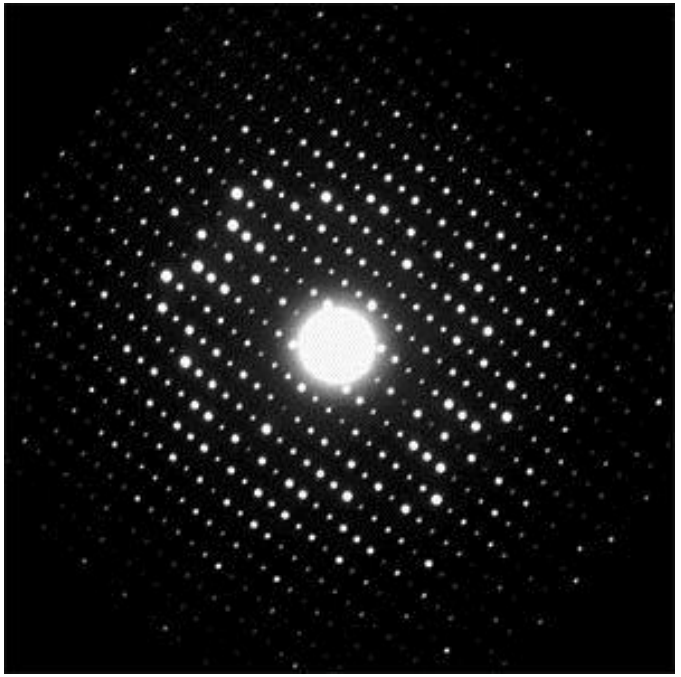
$d = 0{,}91 \times 10^{-10}$ m;
$n = 1$; $\theta = 65^o$
$\lambda = 2 \times 0{,}91 \times 10^{-10} \times \sin 65^o =$
1,65 Å

Comprovação Experimental



C. H. Jönsson
1960





Padrão de difração de elétrons em um cristal de ***óxido de tântalo inorgânico***

Exercícios

1) Determine o comprimento de onda de ***de Broglie*** para o caso de uma bola de futebol com massa de 445g, chutada com uma velocidade de 85 km/h. **h = 6,626x10^{-34} J.s**

2) Determine o comprimento de onda de ***de Broglie*** para o caso de um elétron, massa de 9,11 x 10^{-31} kg, submetido a uma ddp de 100V (calcule v).

Princípio da Incerteza

$$\Delta x.\Delta p \geq \frac{h}{4.\pi}$$

"A posição e o momento linear de uma partícula não podem ser medidos simultaneamente, com uma precisão arbitrariamente alta."

Werner K. Heisenberg
1901 - 1976
Nobel de ***1.932***

3) Você está jogando futebol em um universo (muito diferente do nosso!) no qual a constante de Planck é 0,60 J.s. Qual é a indeterminação da posição de uma bola de 0,50 Kg que foi chutada com uma velocidade de 20 m/s se a indeterminação da velocidade é 1,0 m/s?

Dados:

$h = 0,60\ J \cdot s$

$m_b = 0,50\ Kg$

$v_x = 20\ m/s$

$\Delta v_x = 1\ m/s$

$\Delta x = ?$

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Comprovação Experimental

- Estermann, Stern e Frisch

Todas as partículas materiais apresentam comportamento ondulatório;
difração de feixes moleculares de H e He numa superfície de LiF