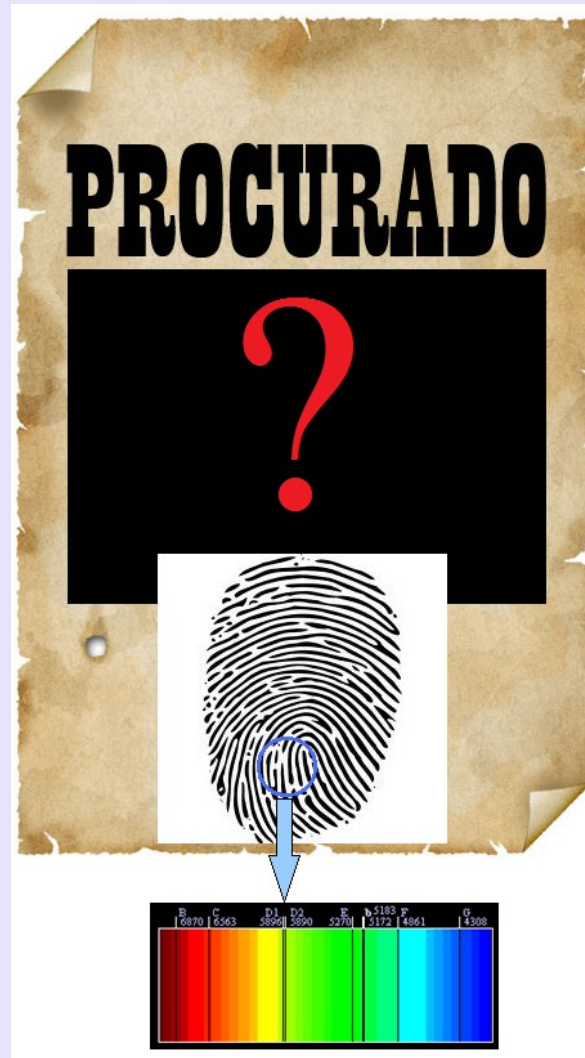
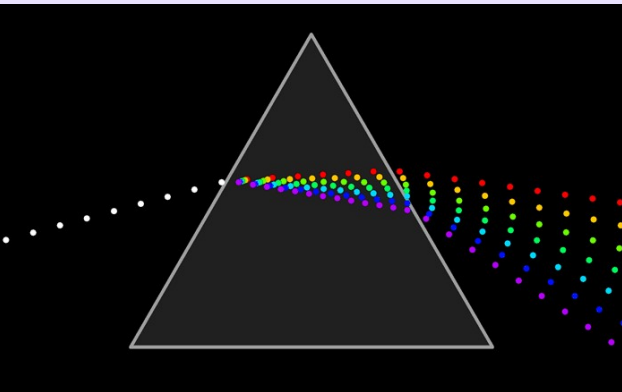
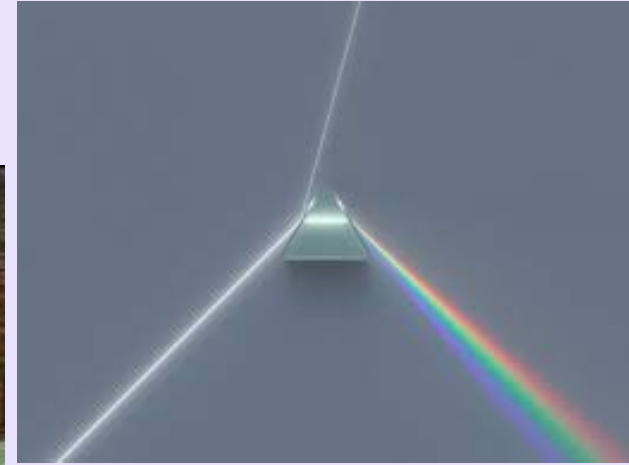


A “Impressão Digital” do Átomo



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Newton e a Dispersão da Luz



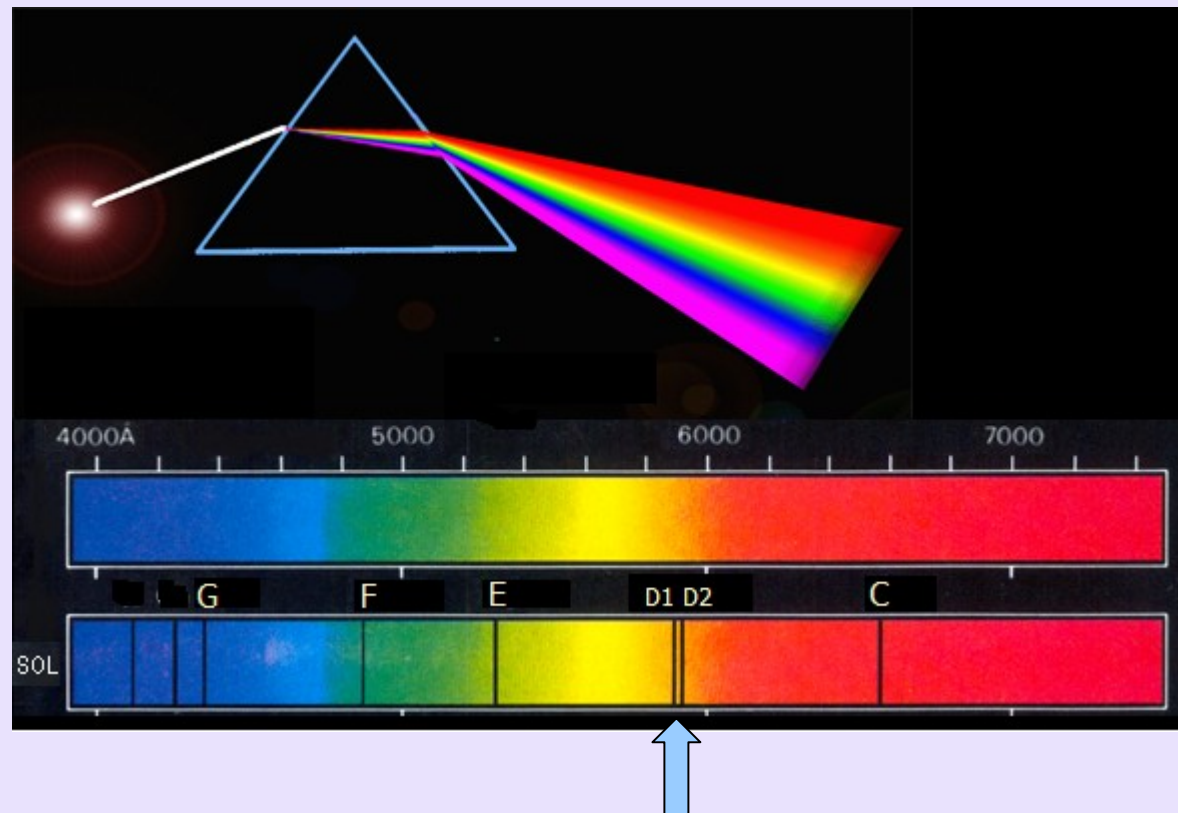
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Espectro Solar e as Linhas de Fraunhofer

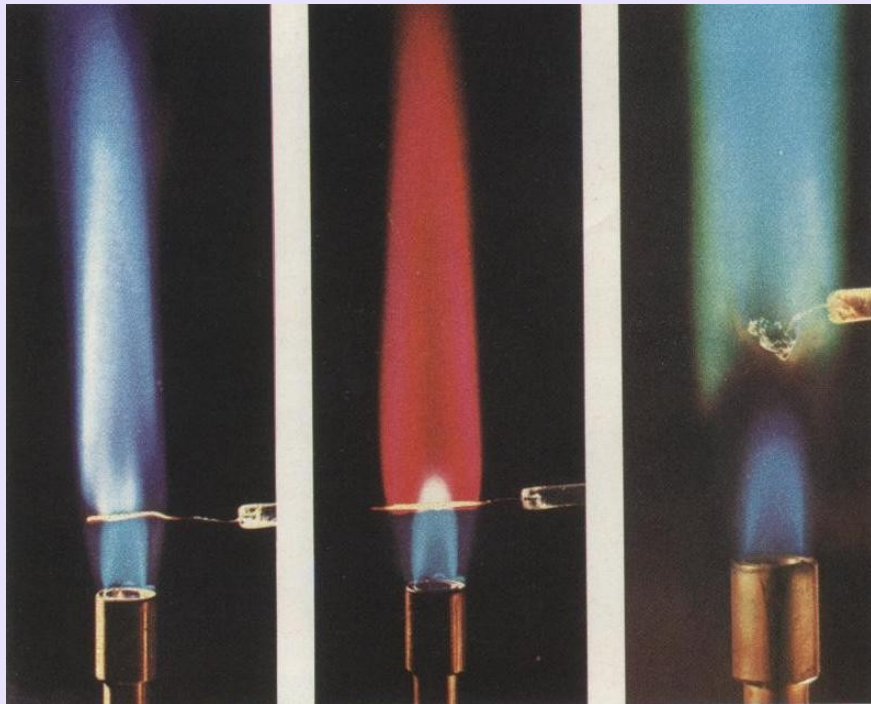


- D1 = 5890 Å
- D2 = 5896 Å

Espectro:
Vênus = Sol
Sirius ≠ Sol



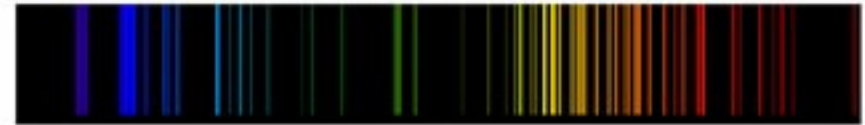
Análise Espectral: Kirchhoff e Bunsen



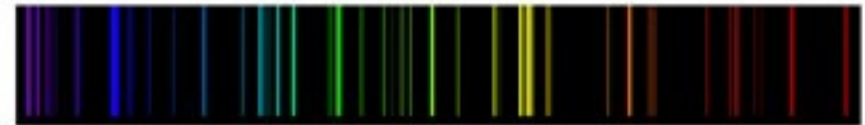
Hidrogênio



Hélio



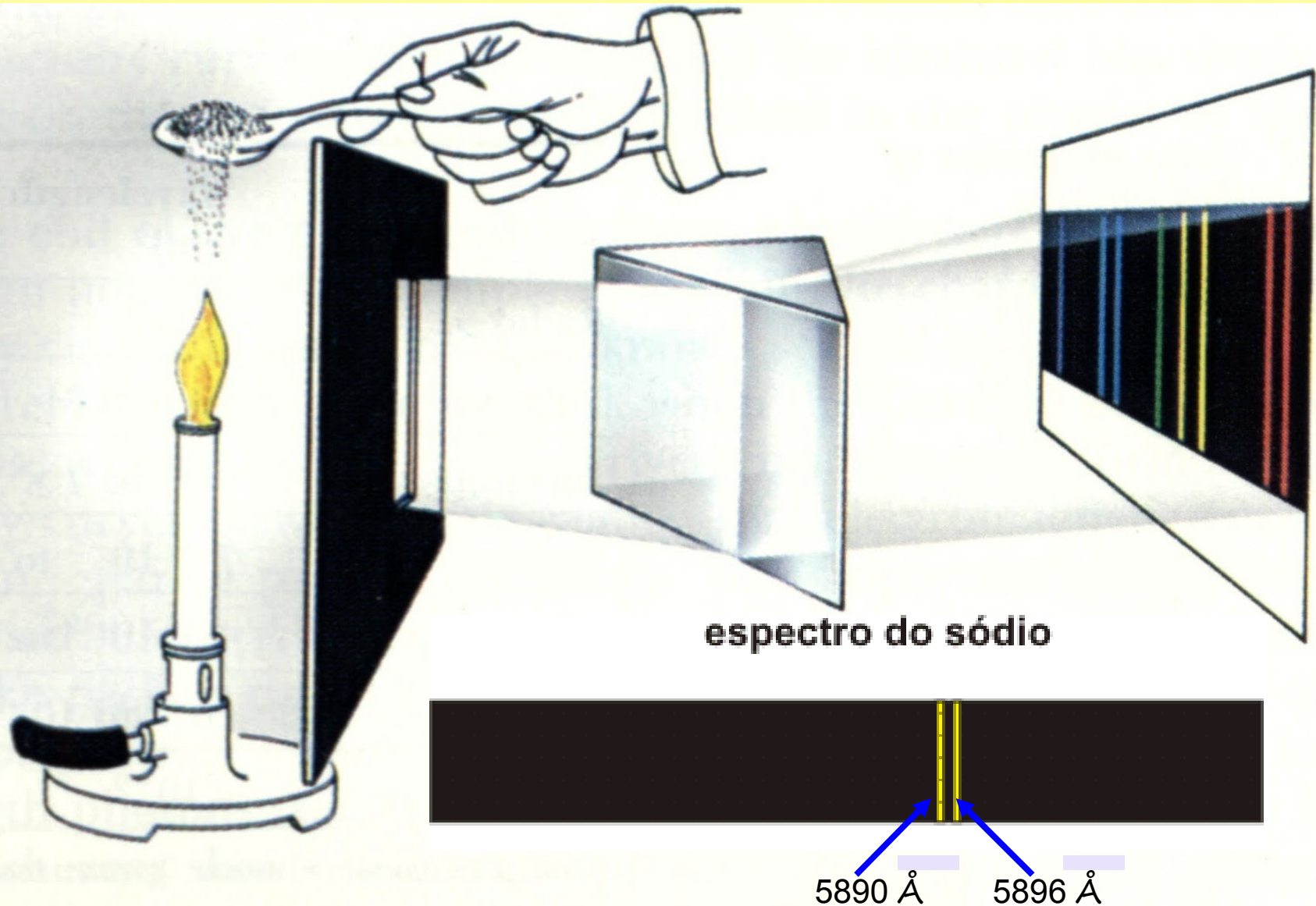
Neônio



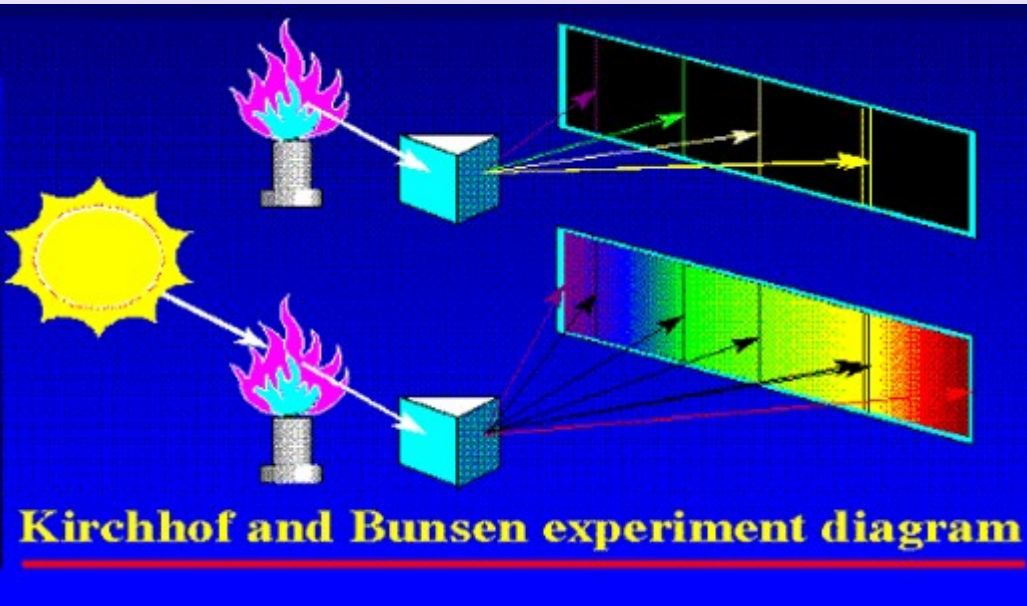
Mercúrio



Análise Espectral: Dubleto de Sódio



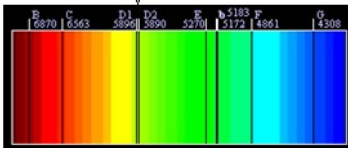
Análise Espectral: Absorção



Encontrado

PROCURADO

?



Fonte de Espectro Contínuo

Sol

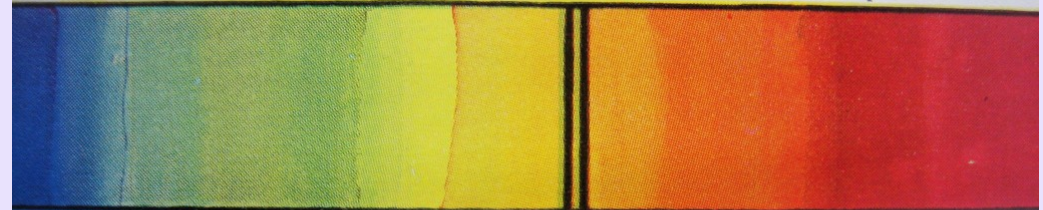
prisma

Atmosfera Solar



Espectro de linhas de absorção

LINE ABSORPTION (SODIUM)

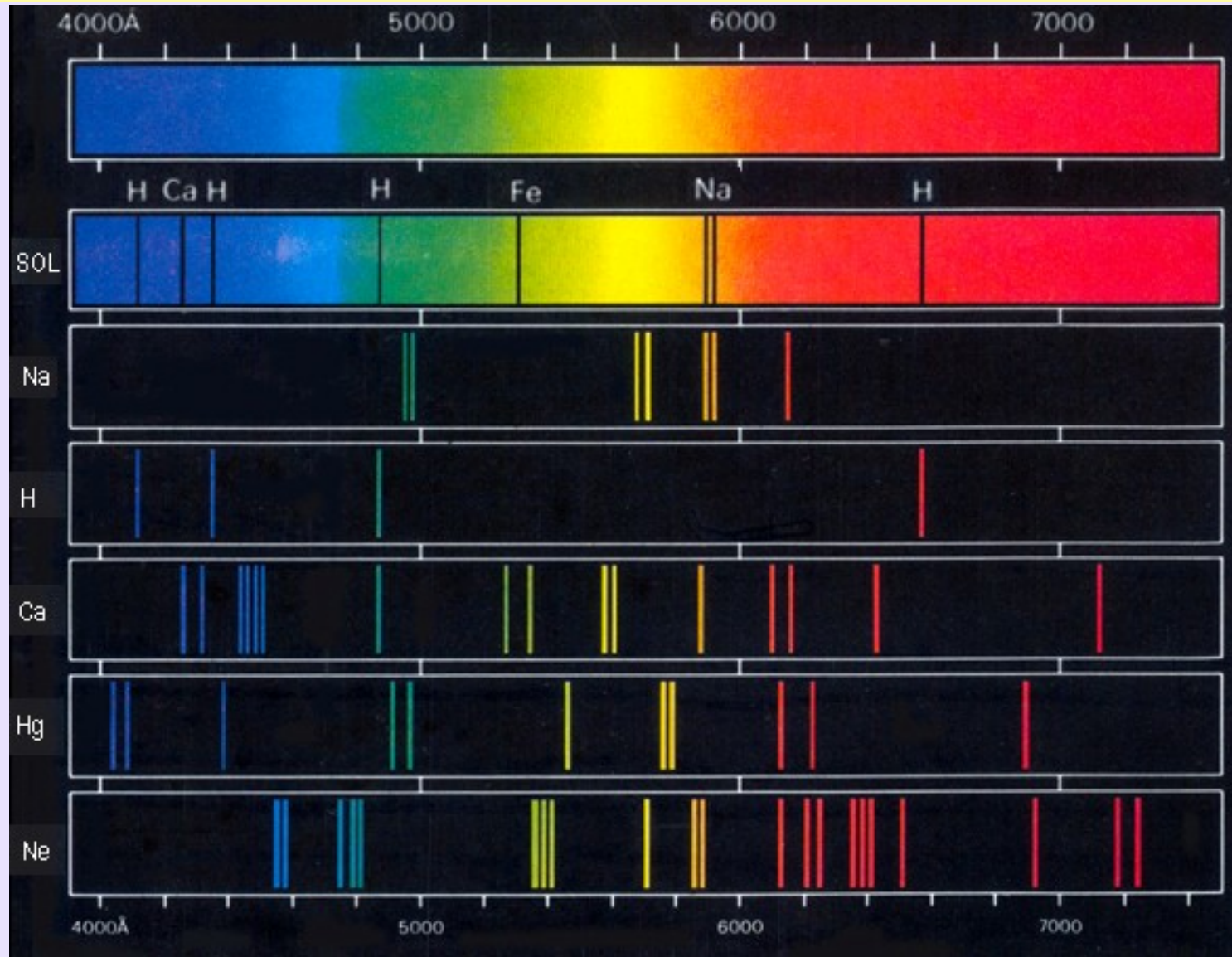


FRAUNHOFER LINES (SUN)



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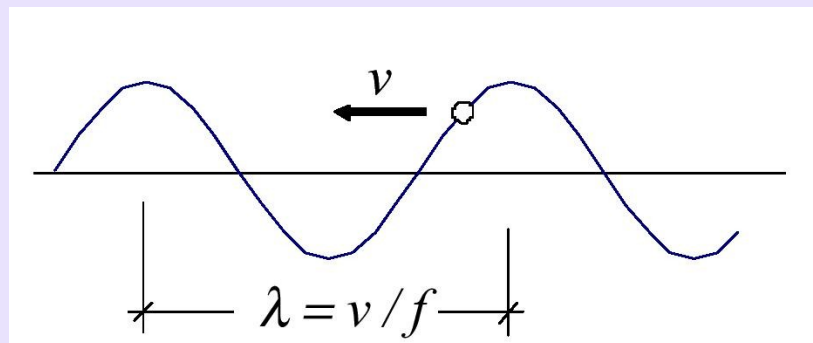
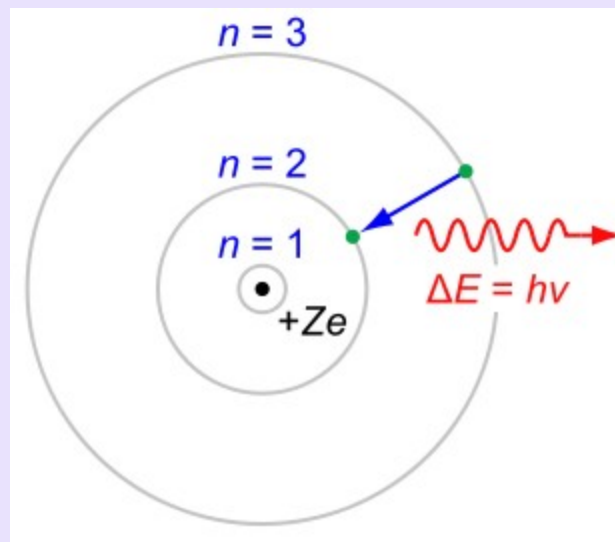
O nascimento da Astrofísica



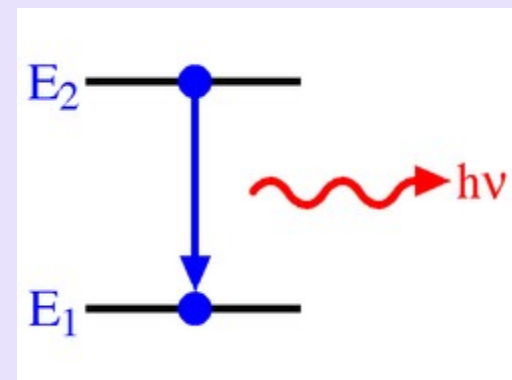
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Modelo Atômico de Bohr

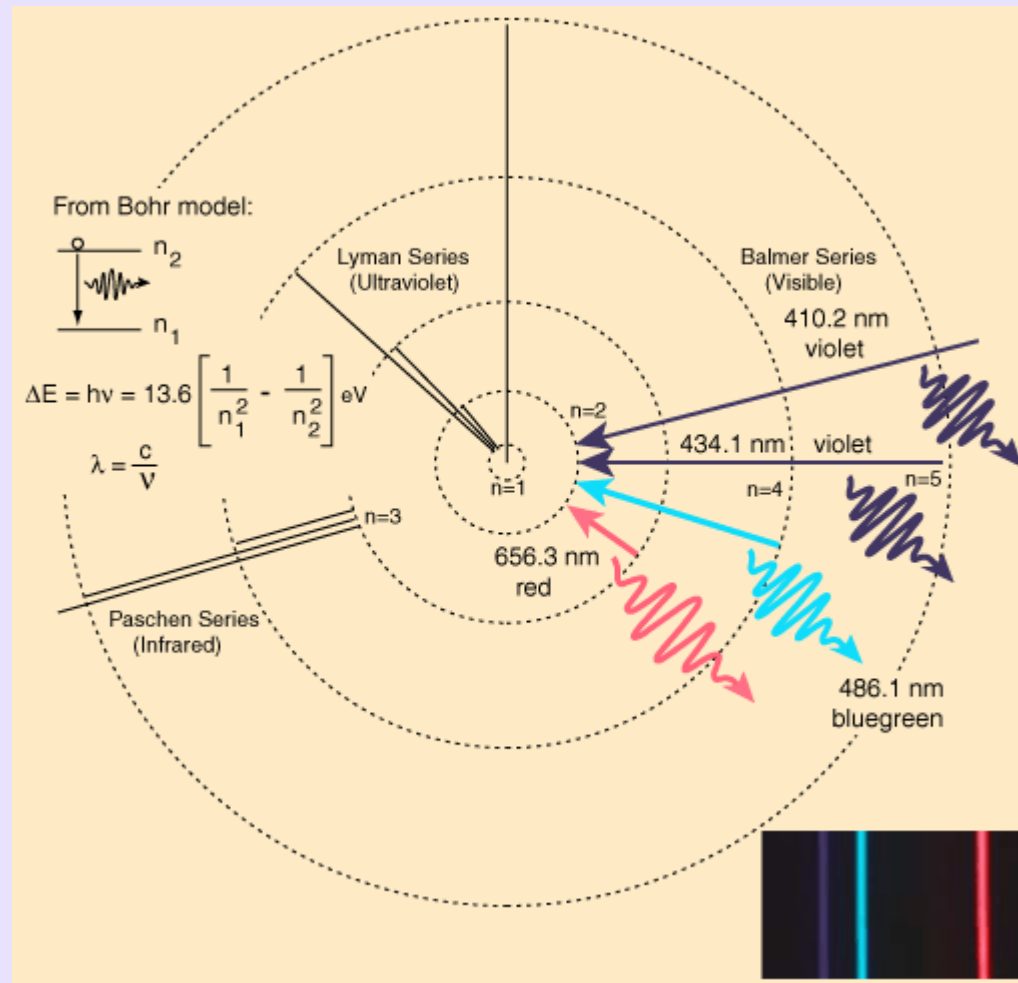
- 1913
- quantização
- frequência proporcional à diferença de energia



$$\Delta E = E_2 - E_1 = h\nu = \frac{hc}{\lambda}$$

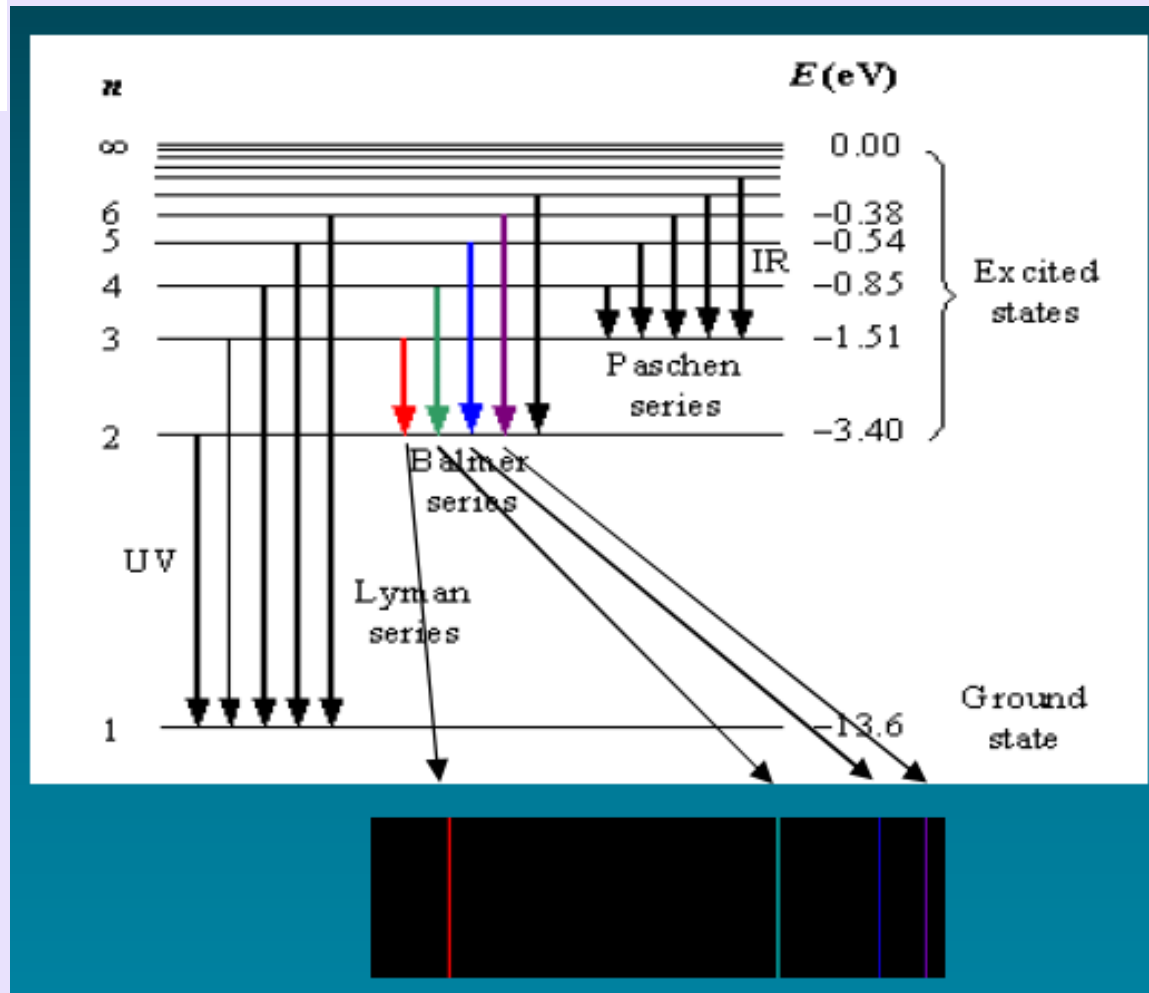


A Interpretação do Espectro Atômico



A Interpretação do Espectro Atômico

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

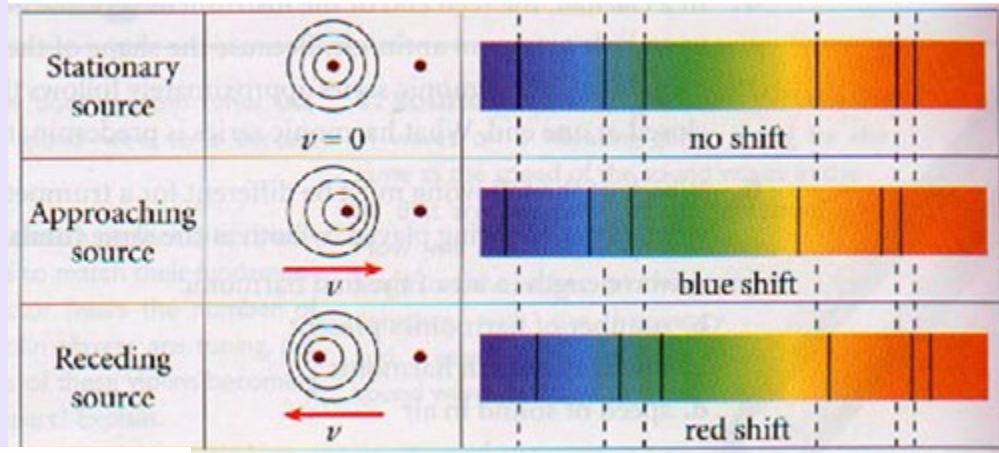


O Efeito Doppler e o Rotação do Sol

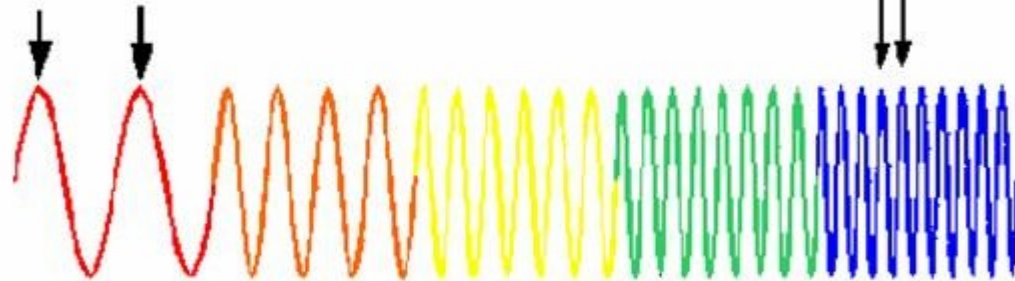
no som



Doppler Effect



Comprimento
de ondas longas



Baixa Frequência
Baixa Energia

Comprimento
de ondas curtas

Alta Frequência
Alta Energia

measuring the relative velocities of stars
by the Doppler shift.



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O Efeito Doppler e o Rotação do Sol

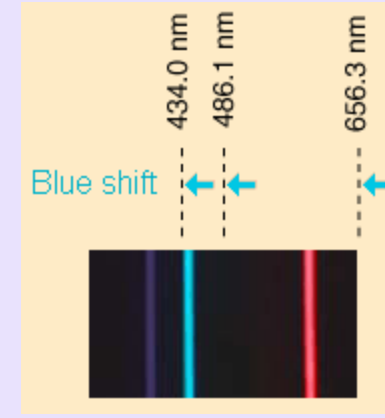
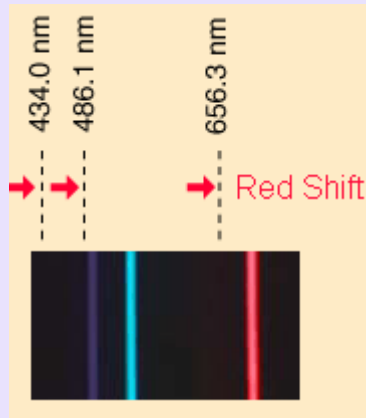
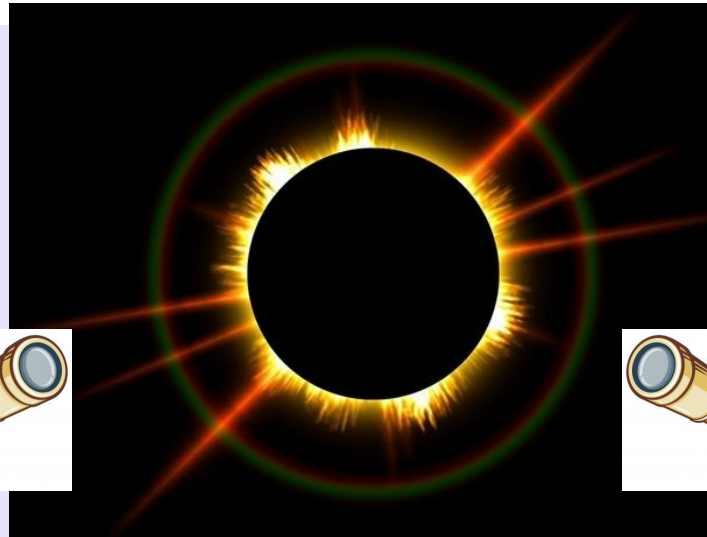
$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

$\Delta\lambda$ = desvio no comprimento de onda

λ_0 = comprimento de onda da fonte parada

v = velocidade relativa da fonte

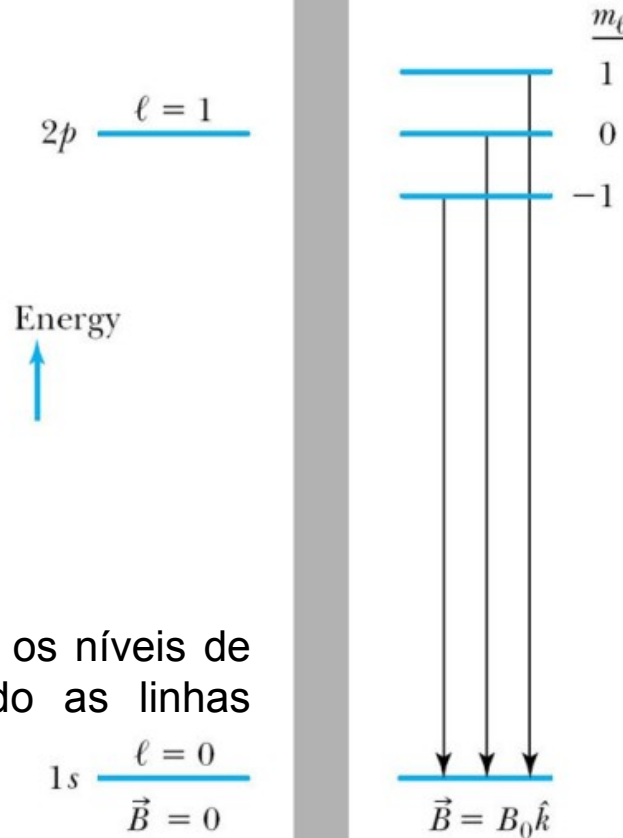
c = velocidade da luz



O Efeito Zeeman e o Campo Magnético das Estrelas

O Efeito Zeeman

A transição de $2p$ para $1s$, separada pelo campo magnético.



Átomo de Hidrogênio



Sem campo magnético

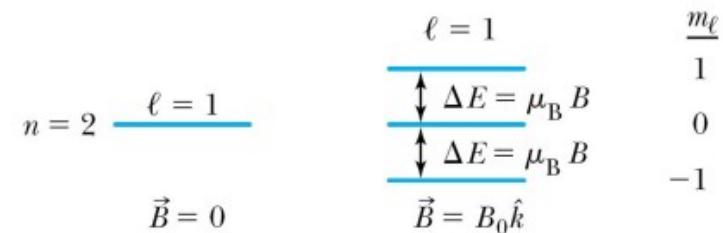


Com campo magnético

O campo magnético altera os níveis de energia atômicos, dividindo as linhas espectrais.

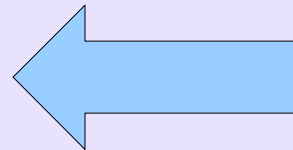
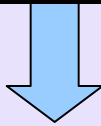
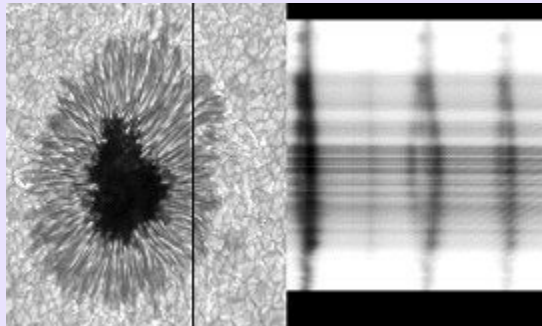
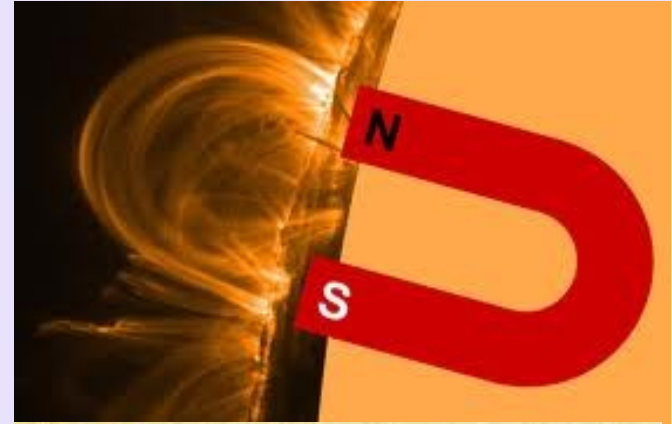
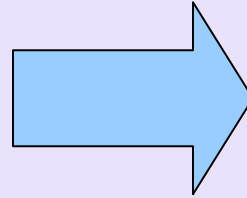
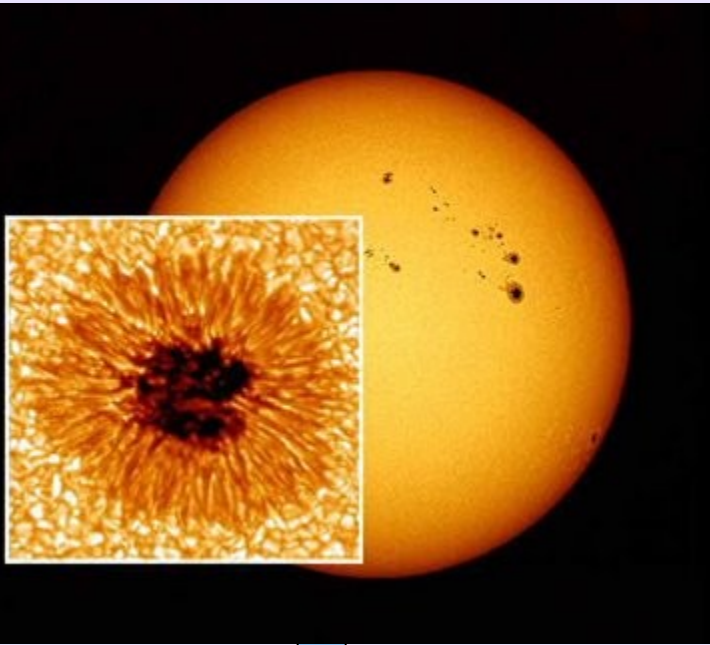
A separação entre as linhas é proporcional à intensidade do campo. Isto permite verificar a presença de campo magnético e determinar sua intensidade.

m_ℓ	Energy
1	$E_0 + \mu_B B$
0	E_0
-1	$E_0 - \mu_B B$



O Efeito Zeeman e o Campo Magnético das Estrelas

Manchas Solares



$$\Delta E = \mu_B B = \frac{hc\Delta\lambda}{\lambda_s\lambda_c}$$



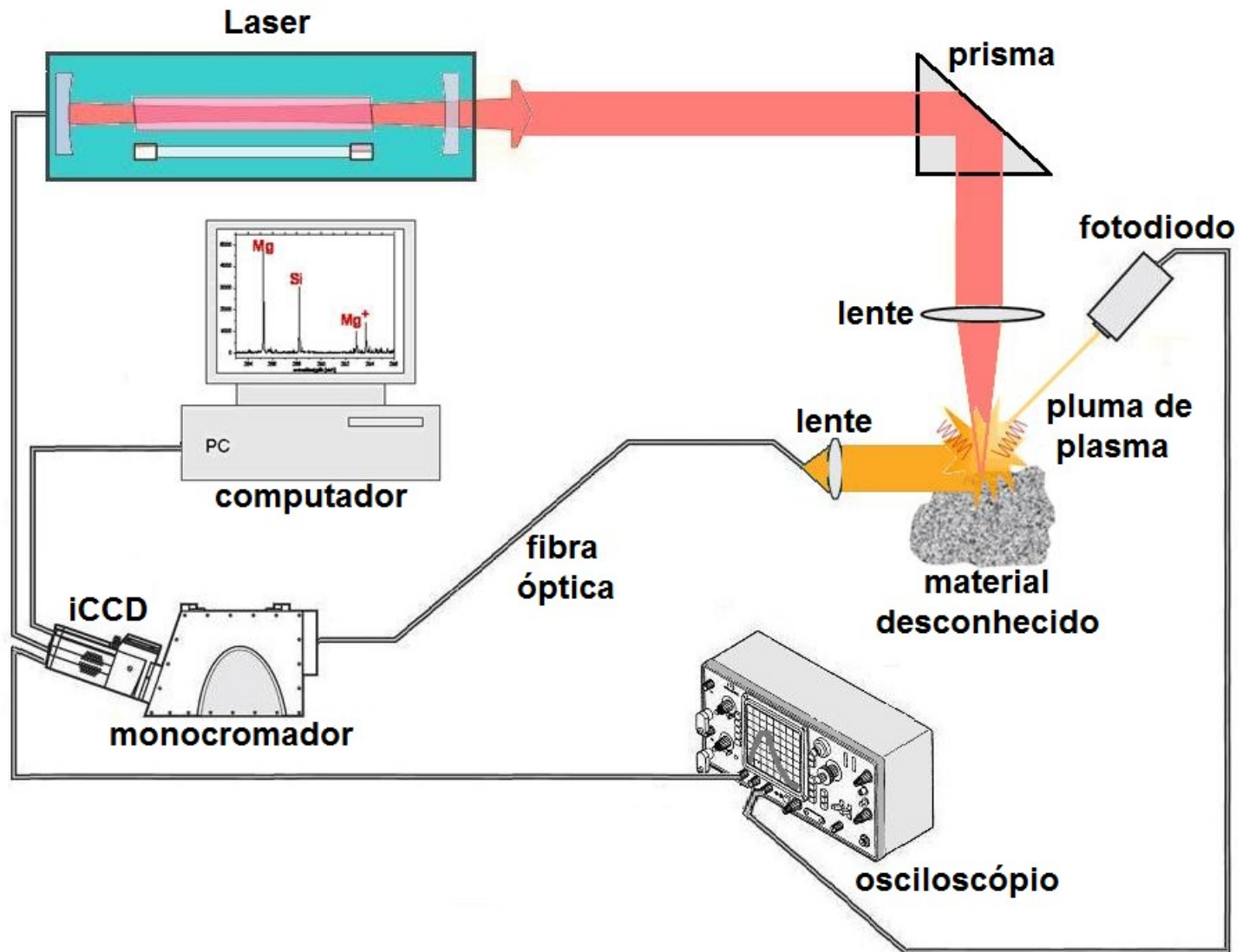
A Técnica “LIBS”

Laser Induced Breakdown Spectroscopy

Fábio de Oliveira Borges

Laboratório de Plasma e Espectroscopia Atômica
Instituto de Física, Universidade Federal Fluminense

EXPERIMENTO

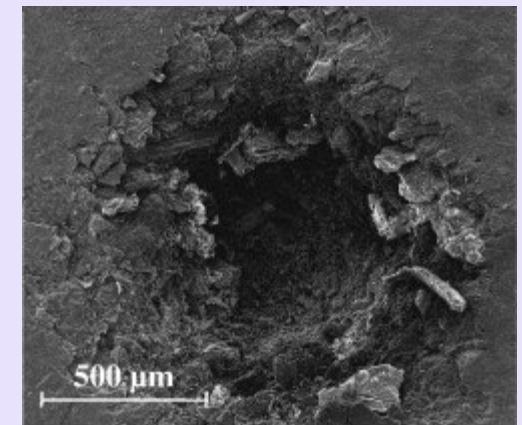
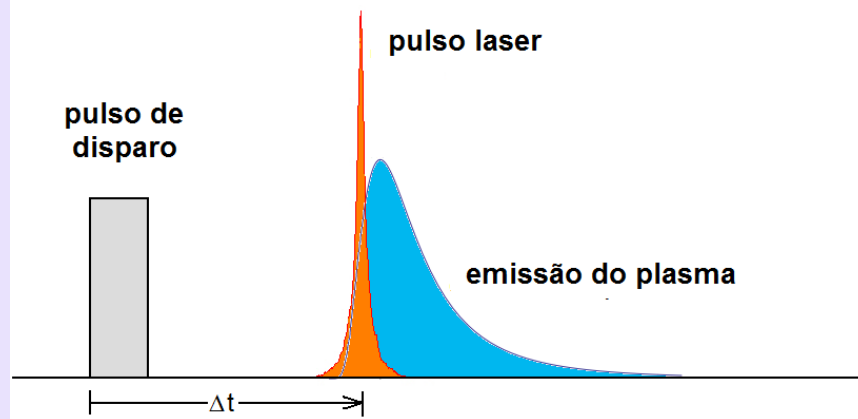
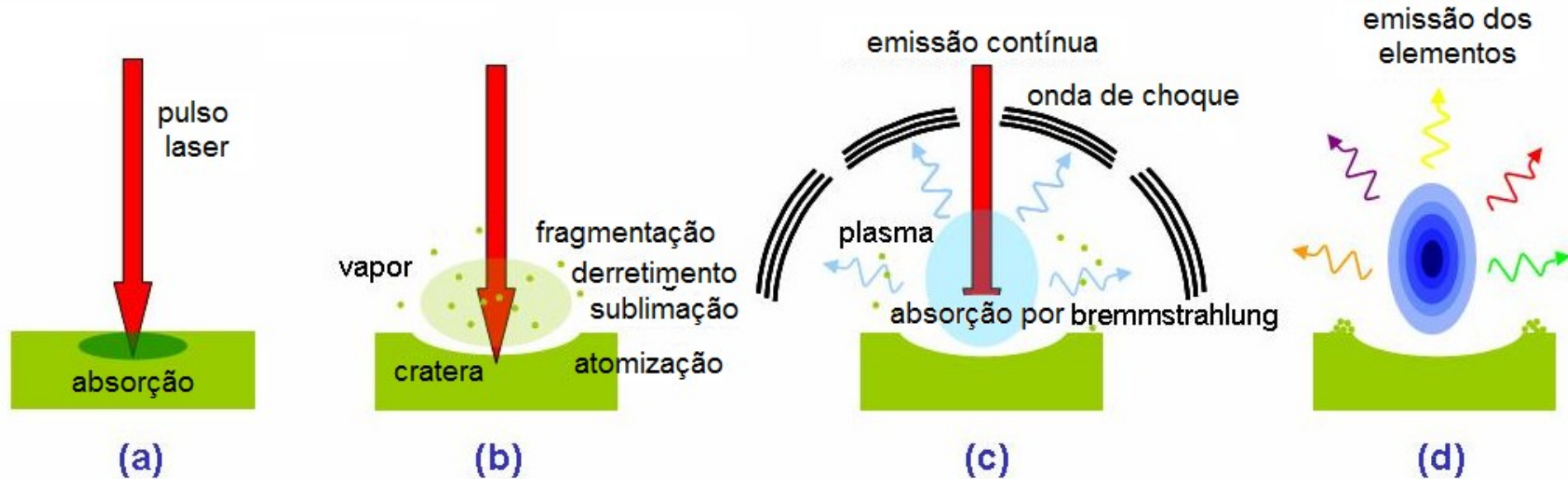


HIPÓTESES

- A composição do volume do plasma sob exame deve representar a composição da amostra (Ablação Estequiométrica)
- O volume do plasma em observação tem que estar em Equilíbrio Termodinâmico Local
- As linhas espectrais observadas tem que ser opticamente finas (plasma transparente a radiação observada)

ABLAÇÃO ESTEQUIOMÉTRICA

Pulsos de nanosegundos $\longrightarrow 10^9 \text{ W/cm}^2$



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EQUILÍBRIO TERMODINÂMICO LOCAL

Leis de equilíbrio em um plasma

- Energia Cinética (velocidades de e^- , íons, átomos neutros)

→ distribuição de Maxwell

- Energia Interna (população dos níveis de energia)

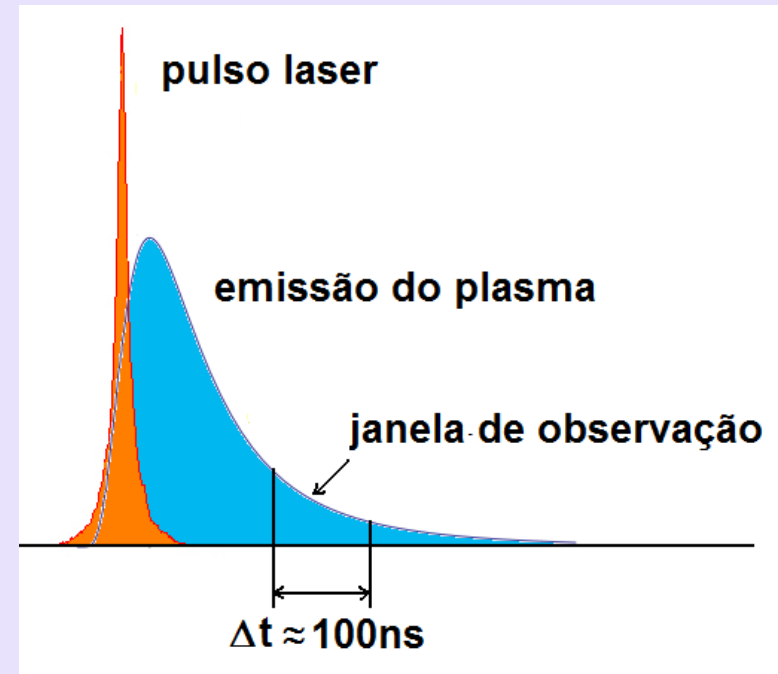
→ distribuição de Boltzmann

- Químico ($A+B \rightleftharpoons AB$)

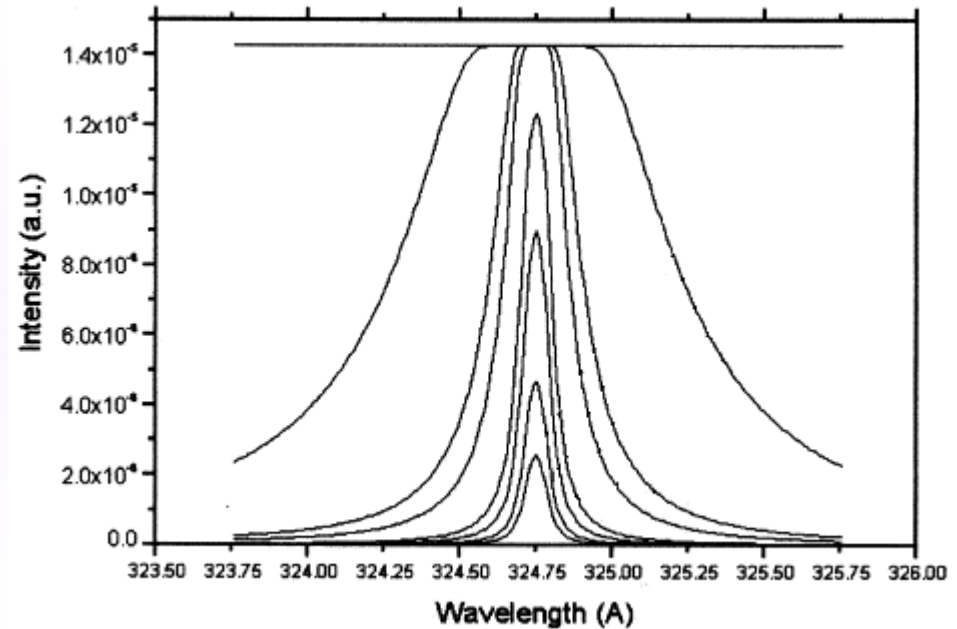
→ equação de Saha (ionização)

~~- Radiação (corpo negro)~~

~~→ equação de Planck~~



AUTO-ABSORÇÃO



Bulajic D et al, Spectrochimica Acta Part B 57 (2002) 339

$$I(\nu, l) = \frac{8\pi hc}{\lambda_{ij}^3} \frac{n_i}{n_j} \frac{g_i}{g_j} \frac{(1 - e^{-\kappa(\nu)l})}{(1 - g_i n_i / g_j n_j)}$$

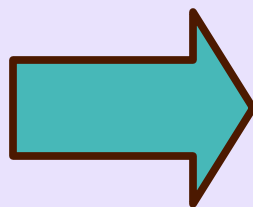
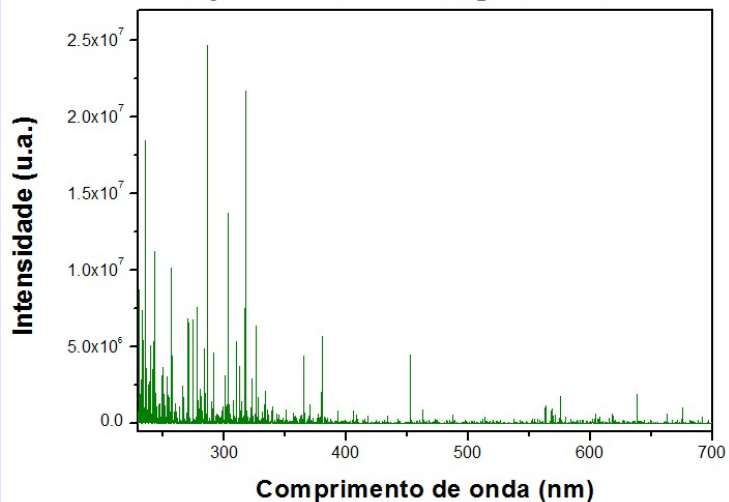
}

$\kappa(\nu)l \ll 1 \longrightarrow I(\nu, l) = h\nu_{ij} A_{ij} n_i g(\nu) l \frac{d\Omega}{4\pi}$

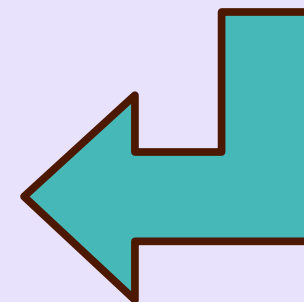
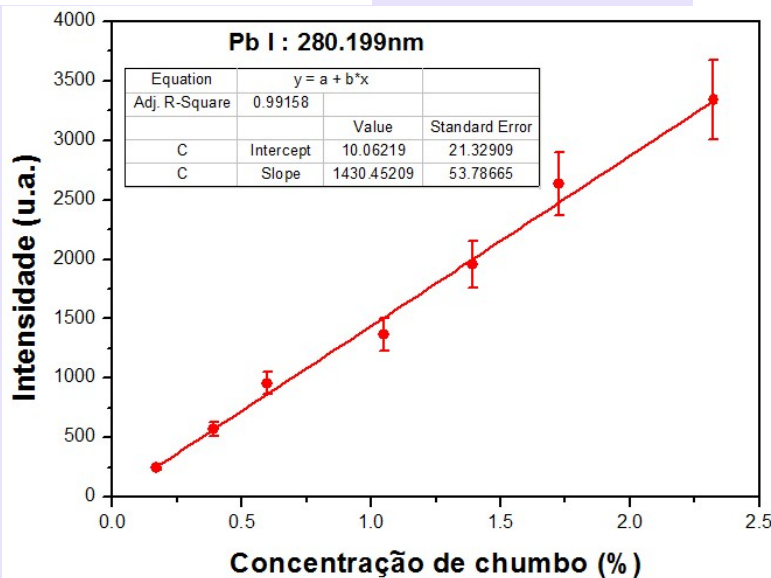
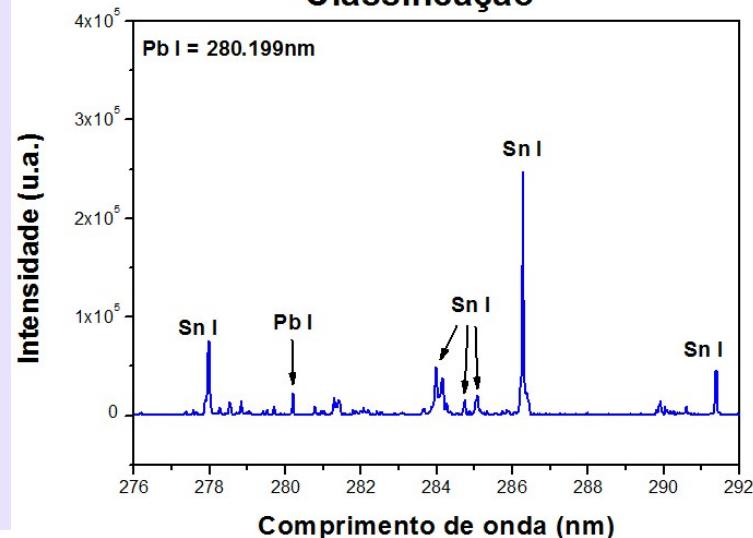
$\kappa(\nu)l \gg 1 \longrightarrow I(\nu, l) = \frac{8\pi h\nu^3}{c^2} \frac{1}{e^{h\nu/k_B T} - 1}$

CURVA DE CALIBRAÇÃO

Espectro de uma liga de SnPb

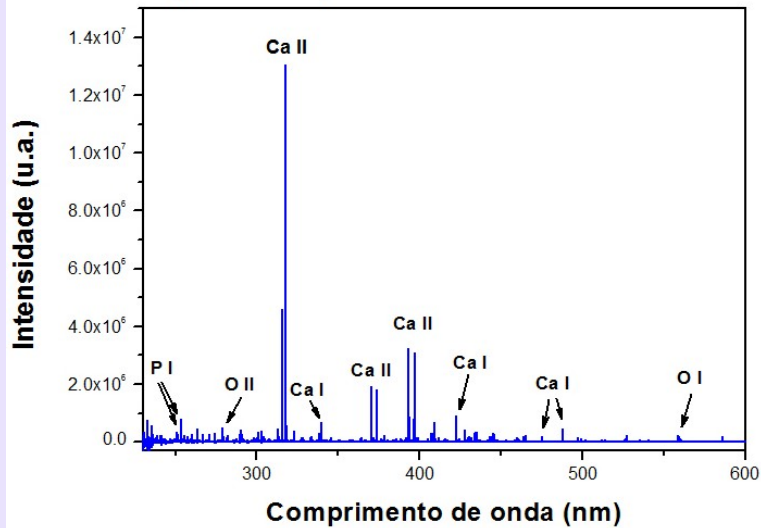


Classificação



CF-LIBS

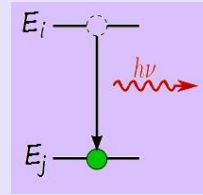
Espectro óptico do fosfato de cálcio



$$C_s = \frac{Q_s(T)}{F} e^{b_s}$$

$$\sum C_s = \frac{1}{F} \sum Q_s(T) e^{b_s} = 100$$

$$C_M^T = C_M^{(I)} + C_M^{(II)}$$

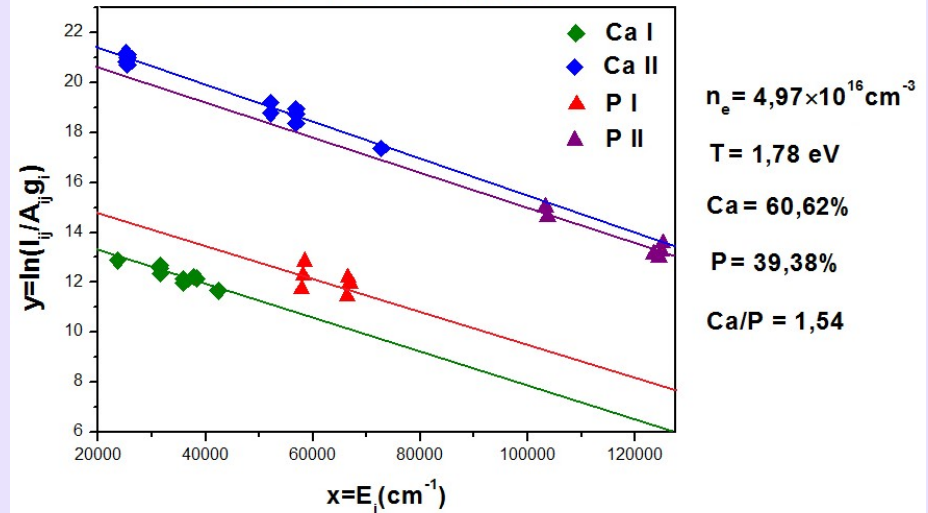


$$I_{ij} = F C_s A_{ij} g_i \frac{e^{-(E_i/K_B T)}}{Q_s(T)}$$

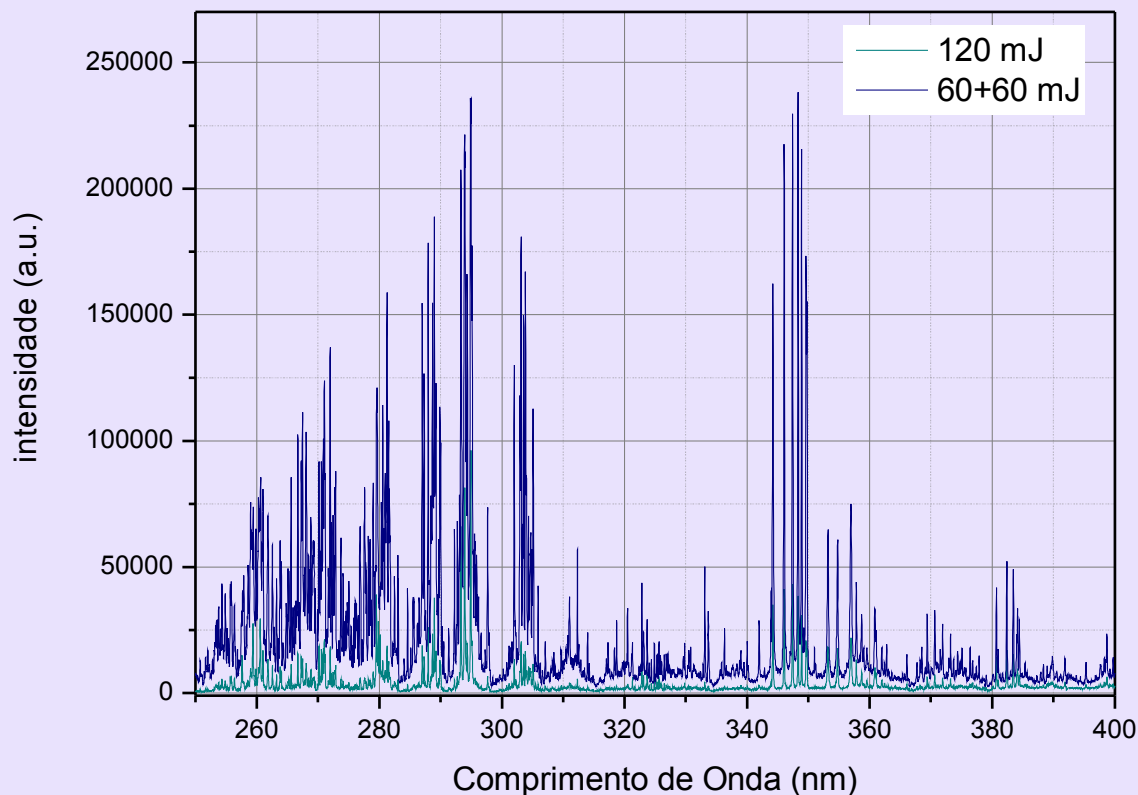
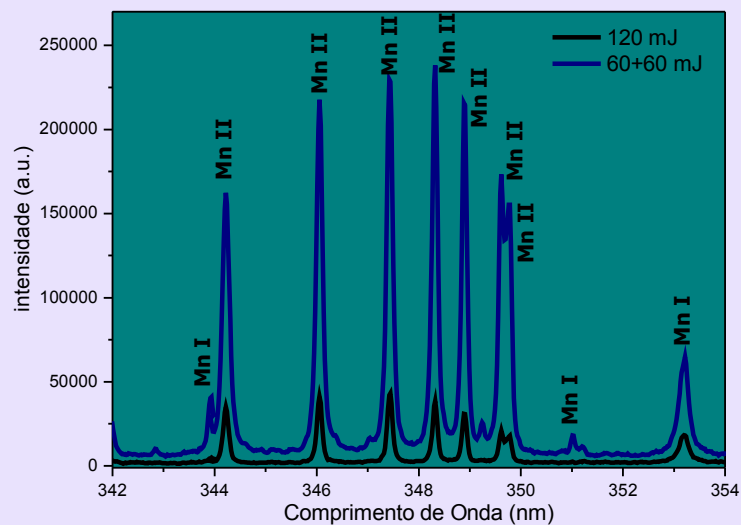
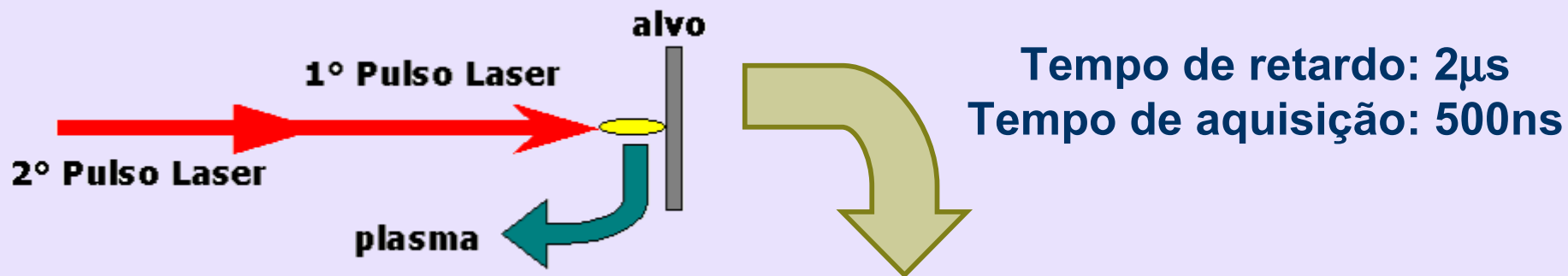
$$y = ax + b$$

$$\ln \frac{I_{ij}}{g_i A_{ij}} = - \frac{1}{K_B T} E_i + \ln \frac{C_s F}{Q_s(T)}$$

Gráfico de Boltzmann



DP-LIBS



LIMITE DE DETECÇÃO

1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984332	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulphur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.945	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine 210	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (264)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113 (284)	114 (289)				
				98 Ce Cerium 140.116	99 Pr Praseodymium 140.90768	100 Nd Neodymium 144.24	101 Pm Promethium (145)	102 Sm Samarium 150.36	103 Eu Europium 151.964	104 Gd Gadolinium 157.25	105 Tb Terbium 158.92534	106 Dy Dysprosium 162.50	107 Ho Holmium 164.93032	108 Er Erbium 167.26	109 Tm Thulium 168.93421	Yb Ytterbium 173.04	71 Lu Lutetium 174.967
				90 Th Thorium 232.0381	91 Pa Protactinium 231.03689	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

<1ppm

1-10ppm

10-100ppm

100-500ppm

>500ppm

Qualitative

<1ppm
1-10ppm
10-100ppm
100-500ppm
>500ppm
Qualitative



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FIM

MUITO OBRIGADO POR SUA ATENÇÃO !

