Experimental and theoretical determination of temperature in plasmas

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Outlook

- Introduction
- Different temperatures
- Thermodynamic equilibrium
- Spectral lines shapes and temperature
- Temperature dependence of Stark widths
- Conclusion

Introduction

Density dependance on Stark broadening

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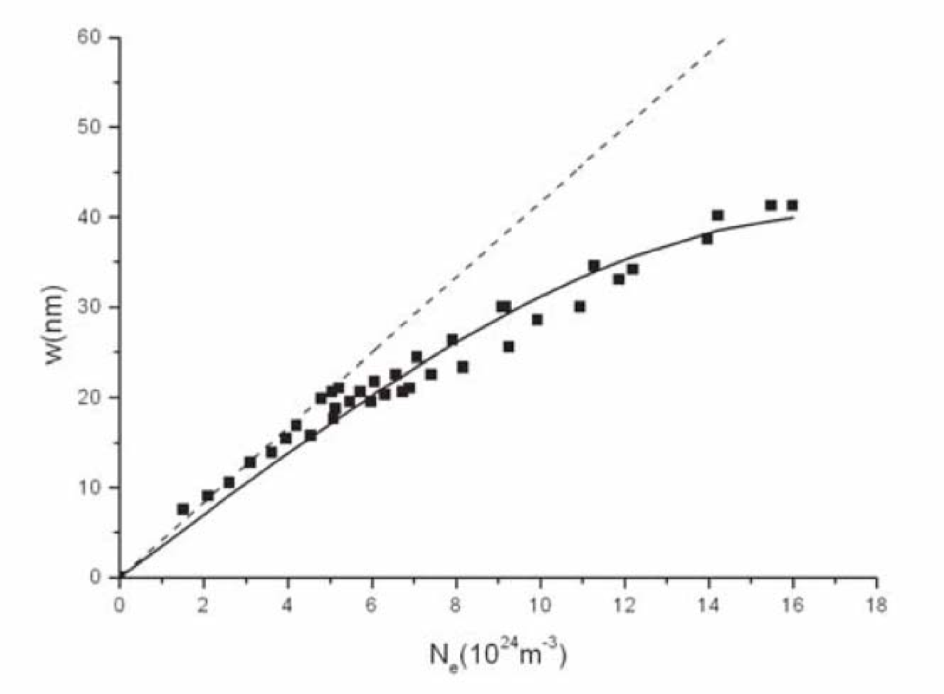

He I 6678 Å

And what about the temperature dependance ?

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Last « born » work !!

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STARK BROADENING OF THE SPECTRAL LINES OF Ne V

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ABSTRACT

Using a semiclassical approach, we have calculated ab initio electron-, proton-, and ionized helium-impact line widths and shift for 26 Ne V multiplets. Energy levels and oscillator strengths have been calculated using SUPERSTRUCTURE code. Results have been presented for an electron density of 10^{17} cm^{-3} as a function of temperature, and are compared with experimental and other theoretical results.

Subject headings: atomic data — atomic processes — line: profiles

Different temperatures

- Kinetic temperature
- Excitation temperature
- Ionization temperature
- Electronic temperature
- Radiation temperature

Kinetic temperature

$$f(v) = 4\pi v^2 \left[\frac{m}{2\pi k T_{kin}} \right]^{3/2} \exp\left(- \frac{mv^2}{2kT_{kin}} \right)$$

Excitation temperature

$$\frac{N_f}{N_i} = \frac{g_f}{g_i} \exp\left(-\frac{E_f - E_i}{kT_{exc}} \right)$$

Ionization temperature

$$\frac{N_e N_i}{N} = \frac{2U_i(T)}{U(T)}\left(\frac{2\pi m_e k T_{ion}}{h^2}\right)^{\frac{3}{2}} \exp\left(-\frac{E_j - \Delta E}{kT_{ion}}\right)$$

Electronic temperature

$$\overline{\varepsilon} = \frac{1}{2} m \overline{v_e}^2 = \frac{3}{2} k T_e$$

Radiation temperature

$$u = u(\nu, T_{rad}) = \frac{8\pi h}{c^3} \frac{\nu^3}{e^{\frac{h\nu}{kT_{rad}}} - 1}$$

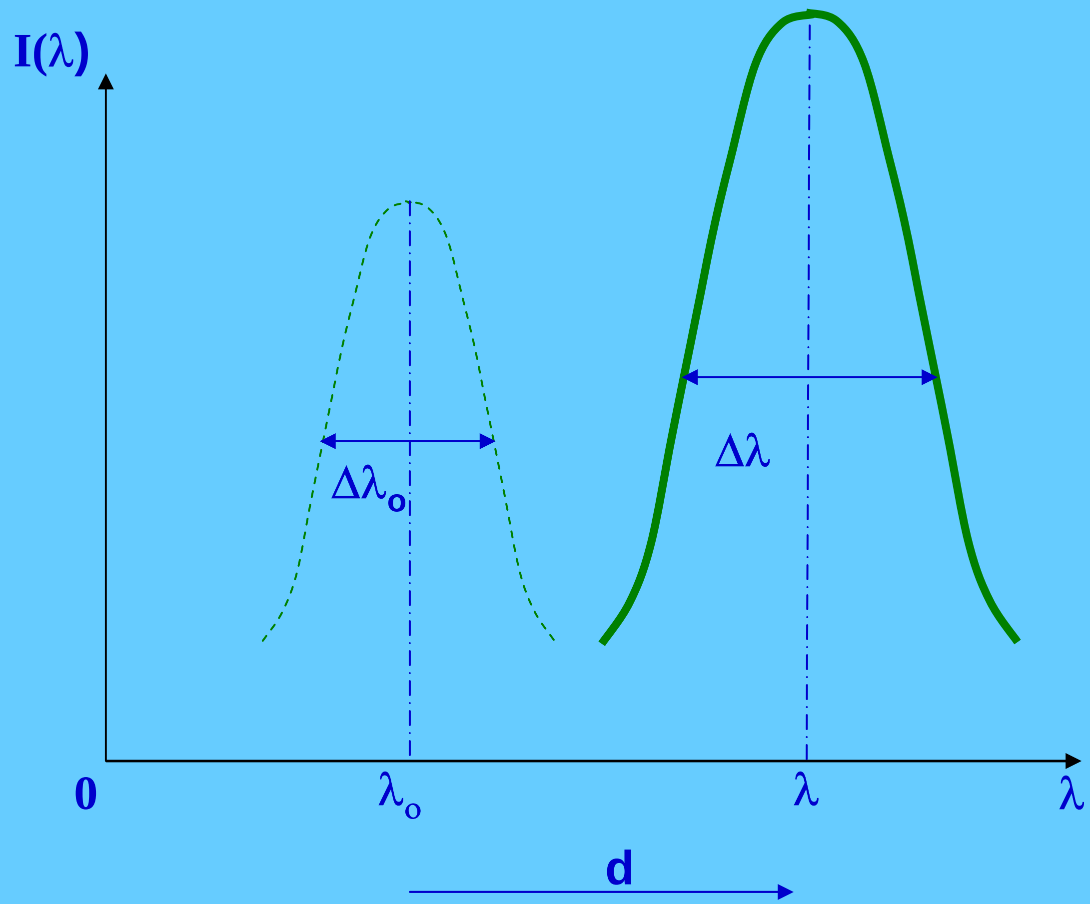
Thermodynamic equilibrium

- Complete Thermodynamic Equilibrium (CTE)

$$\mathrm{T} = T_{kin} = T_{exc} = T_{ion} = T_{e} = T_{rad}$$

- Local Thermodynamic Equilibrium (LTE)

$$T_{kin} = T_{exc} = T_{ion} = T_{e} \neq T_{rad}$$



I(λ)
Δλo
Δλ
0
λo
λ
λ
d

Spectral lines shapes and temperature

Gaussian

- Instrumental
- Doppler

Lorentzian

- Natural
- Van der Waals
- Stark

Doppler effect and temperature

$$G(x) = \sqrt{\frac{\ln(2)}{\pi}} \frac{1}{\gamma_G} \exp\left[-\ln(2) \left(\frac{x}{\gamma_G} \right)^2 \right]$$

$$w_D = 7.17\, 10^{-7} \left[\frac{T_g}{M} \right]^{1/2}$$

Van der Waals effect and temperature

$$L(x) = \frac{1}{\pi \gamma_L} \frac{\gamma_L^2}{\left(x^2 + \gamma_L^2\right)}$$

$$w_{VdW} = 8.18\,10^{-26} \lambda^2 \left(\alpha \left\langle \overline{R^2} \right\rangle\right)^{2/5} \left[\frac{T_g}{\mu}\right]^{3/10} N$$

Stark effect and temperature

$$j_{A,R}(x) = \frac{1}{\pi}\int_0^{\infty} \frac{W_R(\beta)}{1+\left(x - A^{4/3}\beta^2\right)^2}\, d\beta$$

$$W_{iq} = 1.75\ 10^{-4} N_e^{1/4} A[1 - 0.068 N_e^{1/6} T^{-1/2}] W_e$$

and

$$d_{iq} = 1.\ 10^{-4} N_e^{1/4} A[1 - 0.068 N_e^{1/6} T^{-1/2}] W_e$$

where T is in Kelvin and N_e in cm^{-3}.

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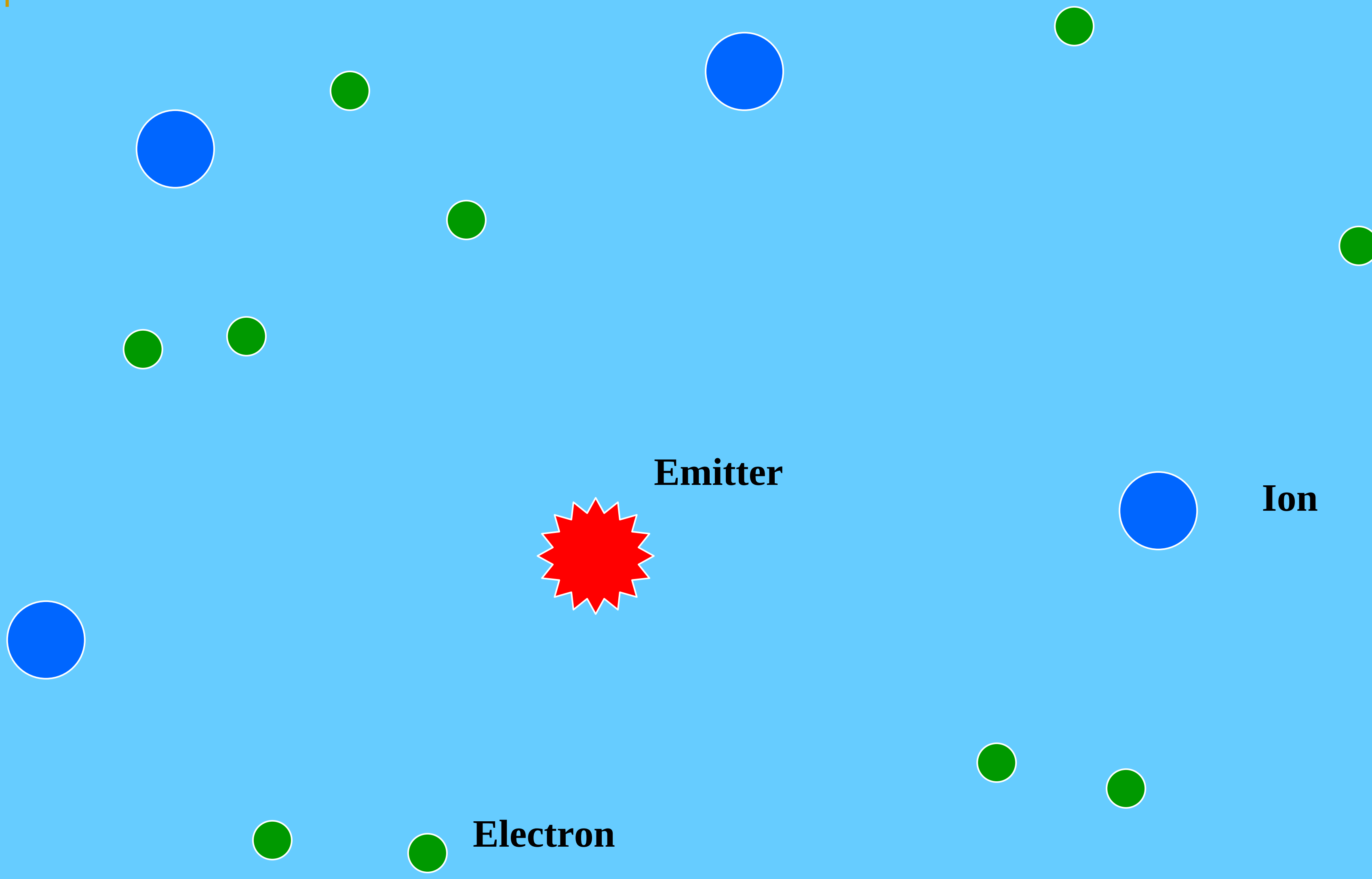
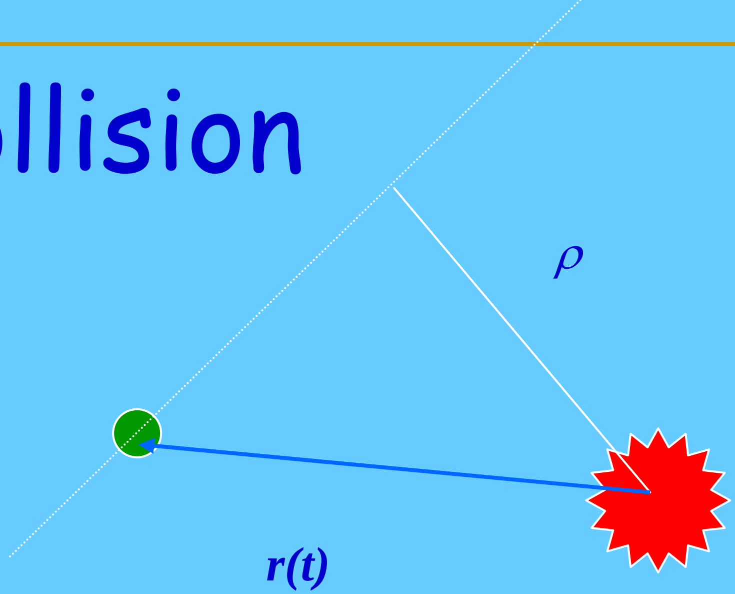

Emitter
Ion
Electron

Electronic collision



w_e = largeur électronique totale à mi-hauteur (HWHM)

$$w_e = N\int_0^{\infty} v f(v) dv \left[\sum_{i'} \sigma_{ii'}(v) + \sum_{f'} \sigma_{ff'}(v) + \sigma_{el}(v) \right]$$

$$\sum_{j' \neq j} \sigma_{jj'}(v) = \pi R_1^2 \sum_{j' \neq j} P_{jj'}(R_1, v) + \int_{R_1}^{R_D} 2\pi\rho d\rho \sum_{j' \neq j} P_{jj'}(\rho, v)$$

$$P_{jj'}(\rho, v) = \frac{1}{\hbar^2} \left| \int_{-\infty}^{+\infty} \langle i | V(t) | f \rangle e^{\frac{i(E_j - E_i)t}{\hbar}} dt \right| \qquad V(t) = -e\overrightarrow{r_a} \cdot \overrightarrow{E}(t) = -e^2 \frac{\overrightarrow{r_a} \cdot (vt\vec{u} + \rho\vec{v})}{(\rho^2 + v^2 t^2)^{3/2}}$$

Different methods for scaling with temperature

$$w = \frac{w_o}{\sqrt{T}}$$

$$w = A_o T^{A_1}$$

$$w = A + BT^{-C}$$

Electronic widths for neutral Helium

Transition	T	w_G	w_{DSB}
$2s^1S-2p^1P^0$ 20581.3 Å	5000	0.364	**0.375**
	10000	0.433	**0.399**
	20000	0.514	**0.438**
	40000	0.590	**0.500**
$2s^1S-3p^1P^0$ 5015.7 Å	5000	0.378	**0.317**
	10000	0.359	**0.300**
	20000	0.334	**0.286**
	40000	0.306	**0.268**

Simplified formula (FC78-DK86)

$$w + id = \left(\frac{32}{27}\right)^{1/2} N_e \pi \left(\frac{\hbar a_o}{m}\right)\left(\frac{E_H}{kT}\right)^{1/2} \left\{ R_{ii'}^2 \left(f_w(\eta_{ii'} R_{ii'}) + i\varepsilon_{ii'} f_d(\eta_{ii'} R_{ii'}) \right) \right\}$$

$$f_w(x) = e^{-1.33x} \ln\left(1 + \frac{2.27}{x}\right) + \frac{0.487\,x}{0.153 + x^{5/3}} + \frac{x}{7.93 + x^3},$$

$$f_d(x) = 1.571\, e^{-2.482x} + \frac{1.295\,x}{0.415 + x^{5/3}} + \frac{0.713\,x}{8.139 + x^3},$$

where $x = \eta_{jj'} \boldsymbol{R}_{jj'}$.

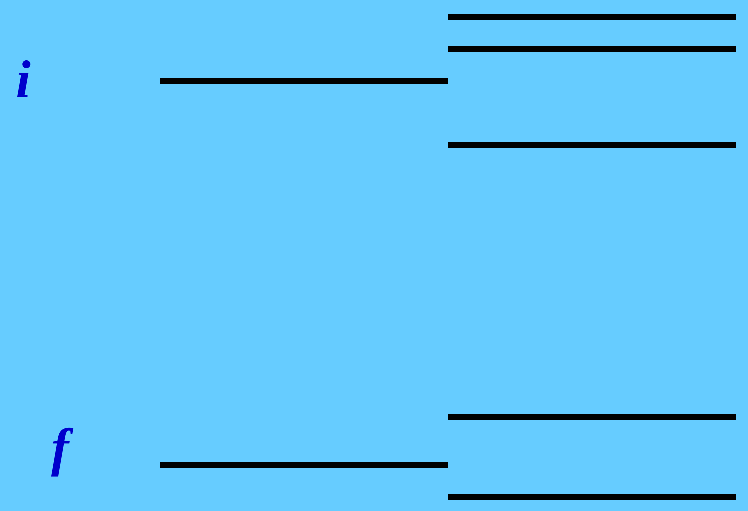
$$\eta_{jj'} = \frac{\Delta E_{jj'}}{3kT}$$

Temperature dependence of Stark widths

$$w = \frac{c_1}{\sqrt{T}} (R^2{}_{ii'}) f_{ii'}(T)$$

$$w = \frac{c_1}{\sqrt{T}} \left[\sum_{i' \neq i} (R^2{}_{ii'}) f_{ii'}(T) + \sum_{f' \neq f} (R^2{}_{ff'}) f_{ff'}(T) \right]$$

$$c_1 = \left(\frac{32}{27}\right) N_e \pi \left(\frac{E_H}{k}\right)^{\frac{1}{2}} \left(\frac{\hbar a_0}{m}\right)$$



$$R^2{}_{jj'} = \left(\frac{n_j^{*2}}{2Z^2}\right) \left[5 n_j^{*2} + 1 - 3(l_j + 1) \right], \; j = i, f$$

Temperature dependence of Stark widths

$$f_{jj'}(T \ll T_0) = 0.487\left(\frac{3kT}{R_{jj'}\Delta E_{jj'}}\right)^{\frac{2}{3}}$$

$$f_{jj'}(T \gg T_0) = \ln\left(\frac{6.81kT}{R_{jj'}\Delta E_{jj'}}\right)$$

$$T_0 = T_{0jj'} = \left(\frac{\Delta E_{jj'} R_{jj'}}{3k}\right)$$

Temperature dependence of Stark widths

$$f_{jj'}(T) = \frac{3}{4}\ln\left[1+\alpha_{jj'}T^{\frac{2}{3}}+\beta_{jj'}T^{\frac{4}{3}}\right]$$

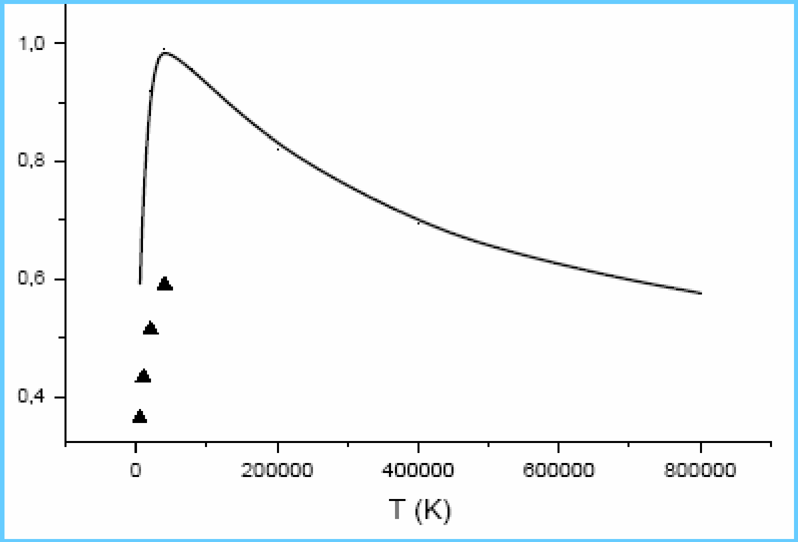
$$\alpha_{jj'} = 0.649\times\left(\frac{3k}{R_{jj'}\Delta E_{jj'}}\right)^{\frac{2}{3}}$$

$$\beta_{jj'} = 2.983\times\left(\frac{3k}{R_{jj'}\Delta E_{jj'}}\right)^{\frac{4}{3}}$$

$$w(T) = w_o\frac{N_e}{\sqrt{T}}\ln\left[1+AT^{\frac{2}{3}}+BT^{\frac{4}{3}}\right]$$

Conclusion

$$w(T) = w_o \frac{N_e}{\sqrt{T}} \ln\left[1 + AT^{\frac{2}{3}} + BT^{\frac{4}{3}}\right]$$



$$w(T >> T_o) = \frac{w_o}{\sqrt{T}} \ln(T)$$

He I 20581.3 Å

شكرا جزيلا للإنتباه

Thank you for your attention

Merci de votre attention

HVALA