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OPACITY CALCULATIONS OF LOW Z PLASMAS FOR ICF

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1. Introduction

In this work we analyze the behavior of Planck and Rosseland mean opacites of carbon plasmas in a wide range of temperature and densities to propose simple analytical expressions for these quantities. Carbon is one of the most interesting elements under investigation, since it is likely to be a major plasma-facing wall component in ITER, and it plays a major role in inertial fusion scenarios. The opacity data are computed under the detailed-level-accounting approach through the use of the code ABAKO/RAPCAL a kinetic code developed by our research group based in a collisional-radiative steady state model covering corona, NLTE and LTE situations. This code has been successfully tested comparing its results with other proven codes in the fourth and fifth Kinetic Code Comparison Workshops. It also has demonstrated to be useful for diagnostic of experiments as it is described in an oral presentation in this conference.

2. Method of calculation

In this work we have performed a detailed analysis of the mean opacity for Carbon plasma, using high quality atomic data obtained using the code FAC [1]. This code provides atomic magnitudes calculated into the DLA approach, using appropriate coupling schemes and including configuration interaction. The calculation of ionic charge state distributions and level populations are performed by means of solving the Saha-Boltzmann equations for LTE and a collisional-radiative steady-state model (CRSS) for NLTE cases. The level populations are computed with a reasonable accuracy for plasmas of any element in a wide range of conditions embracing non-LTE, LTE and CE situations. In this paper we have restricted ourselves to LTE cases. The multifrequency opacity is obtained as a sum of the bound-bound, bound free, free-free and scattering contributions

$$\kappa(\nu) = \frac{1}{\rho}\left(\mu_{bb}(\nu) + \mu_{bf}(\nu) + \mu_{ff}(\nu) + \mu_{scatt}(\nu)\right) \quad (1)$$

where the terms are:

Bound-bound $$\mu_{\xi_{i,j}}(\nu) = \frac{\pi}{mc}\left(\frac{e^2}{4\pi\varepsilon_0}\right) N_{\xi_i} f_{\xi_{i,j}} \phi^a_{\xi_{i,j}}(\nu)\left[1 - \frac{N_{\xi_i} g_{\xi_j}}{N_{\xi_j} g_{\xi_i}}\right] \quad (2)$$

Bound-free $$\mu_{\xi_i,\xi+1_j}(\nu) = N_{\xi_i}\sigma(\nu)_{\xi_i,\xi+1_j}\left[1 - \frac{N_{\xi+1_j} g_{\xi_i}}{N_{\xi_i} g_{\xi+1_j}}\right] N_e n(\varepsilon, T) \quad (3)$$

Free-free $$\mu_{ff}(\nu) = \frac{32\pi e^4 a_0^2 \alpha^3 \bar{z}^2}{2\sqrt{3}(2\pi m)^{3/2}\hbar}\left(\frac{m}{2\pi kT}\right)^{1/2} N_e N_{ion} e^{-h\nu/kT} \quad (4)$$

In these equations, ξ denotes the ionic state and *ij* and $f_{\xi i,j}$ the line transition between the configurations *i* and *j* and its oscillator strength, respectively; $N_{\xi i}$ and $g_{\xi i}$ are the level population and the statistical weight of the configuration *i* respectively. $\phi^a_{\xi_{i,j}}(\nu)$ is a Voigt profile for lineshape which includes Natural, Stark and Doppler widths. The Rosseland and Planck mean opacities are computed by:

$$\frac{1}{\kappa_{Rosseland}} = \int_0^\infty d\nu B'(\nu,T)/\kappa(\nu) \qquad \kappa_{Planck} = \int_0^\infty d\nu B(\nu,T)\left[\kappa(\nu) - \kappa_{scatt}(\nu)\right] \quad (5)$$

where κ_{scatt} is the absorption coefficient contribution by scattering (Thomson cross section), and $B(\nu,T)$ and $B'(\nu,T)$ are the Planck weighting function and its derivative.

3. Results and discussion

Our main goal in this work was to analyze the range of application of analytical expressions found in the literature to model the mean opacity of low Z plasmas. The main expression used to model Rosseland (κ_R) and Planck (κ_P) mean opacities is a power law depending on temperature and density:

$$\kappa_{R,P} = e^a \rho^b / T^c \quad (6)$$

where T is the temperature (eV) and ρ the density in g/cm^{-3}.The definition of the parameter a can change depending on the author. [2, 4]. The values of the parameters are obtained usually by least square fit.

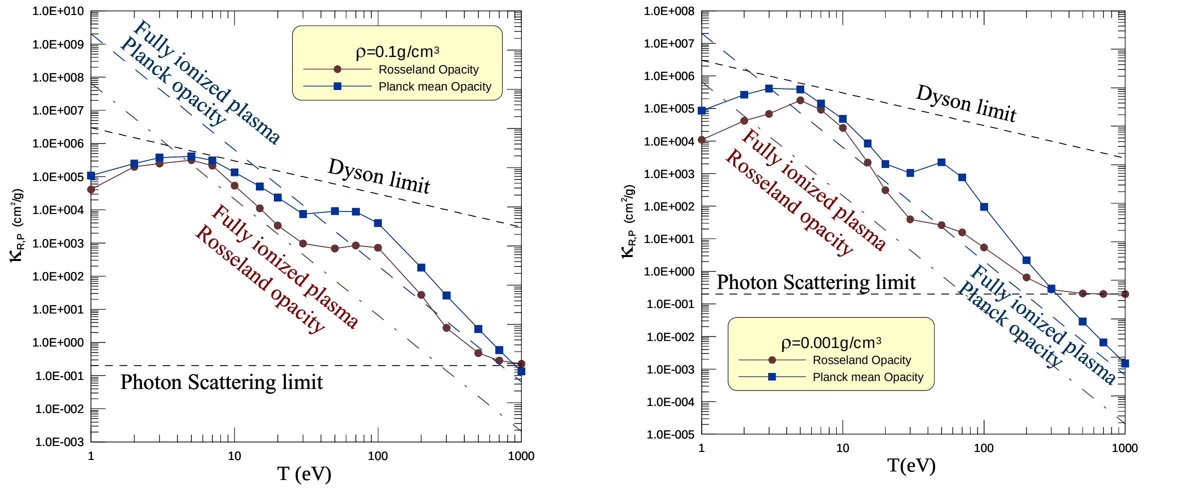

Figure 1. Rosseland and Planck mean opacities ($cm^2 \cdot g^{-1}$) for Carbon versus temperature (eV). Left: ρ = 10^{-1} $g \cdot cm^{-3}$, Right: 10^{-3} $g \cdot cm^{-3}$

In figure 1 we show the Rosseland and Planck mean opacities for Carbon plasmas, as it is well known, these quantities are a decreasing function of the temperature. We show the maximum opacity limit given by the Dyson Formula.

$$\kappa_R \leq 6.0\, Z / AT \quad cm^2/g \tag{7}$$

At high enough temperatures (> 300 eV for the carbon plasma) the photon scattering term dominates being a lower bound for κ_R. We also show the theoretical opacity for fully ionized plasma [6]

$$\kappa_{R,P} = \alpha_{R,P} \left(Z^3 / A^2 \right) \rho T^{-3.5} \quad cm^2/g \tag{8}$$

beingα_{RP}=0.43 (Rosseland), α_{RP}=0.014 (Planck) and T(KeV). Planck mean opacity does not includes the scattering term and in consequence it trends toward this limit for sufficient high temperatures (> 600 eV for the carbon plasma). Thus, the simple power law (9) is not adequate to fit the Rosseland mean opacity since it goes to zero at high temperature. A better formula is obtained by simply adding a constant term κ_{scatt} = *0.4Z/A* (cm^2/g) to that expression. For low temperature this formula in neither valid, it is linear fit in a logarithmic representation and it is clear that both Rosseland and Planck opacities exhibit a complicated behavior in this range (around 1-100 eV for the carbon plasma). A better mach is obtained fitting the mean opacities to third order polynomials in log(T).

$$\log \kappa_R(\rho,T) = \begin{cases} \sum_{n=0}^{3} b_n (\log T)^n & \forall T < T_c \\ \log(\kappa_S) & \forall T < T \end{cases} \qquad \log \kappa_P(\rho,T) = \sum_{n=0}^{3} a_0 (\log T)^n \tag{9}$$

In figure 2 we show the results of the fit for two density cases. As it can be seen it mach the function better than a linear fit like equation (6).

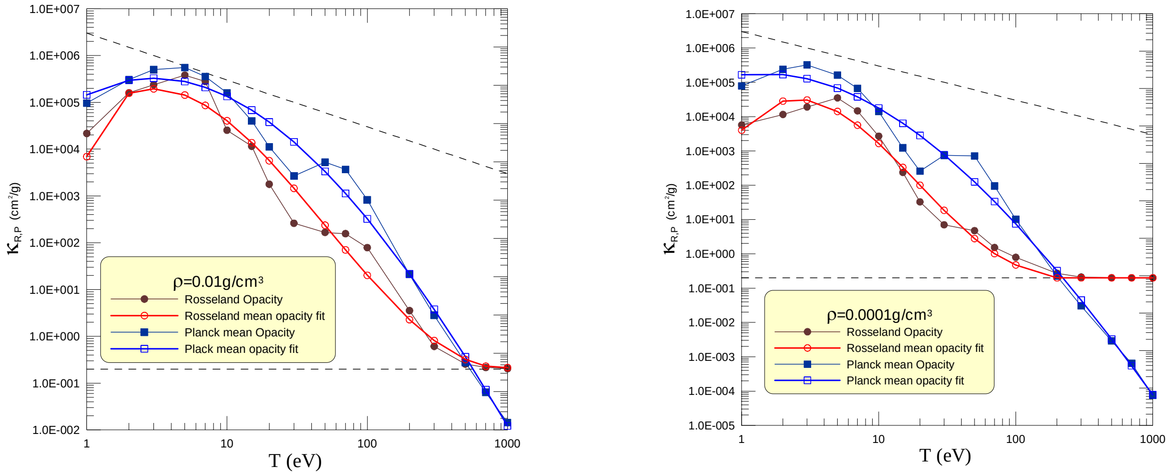

Figure 2. Rosseland and Planck mean opacities ($cm^2 \cdot g^{-1}$) for Carbon versus temperature (eV). Left: $\rho = 10^{-2}$ $g \cdot cm^{-3}$, Right: 10^{-4} $g \cdot cm^{-3}$

In the next table we show the fitting coefficients for several densities. Values for different densities can be obtained by interpolation.

Table 1. Constants for Rosseland and Planck mean opacities.

Density	Rosseland mean				Planck mean			
g/cm^3	b_0	b_1	b_2	b_3	a_0	a_1	a_2	a_3
10^{-1}	0.3686	-2.3436	1.8294	4.861	-0.0421	-0.8141	0.7717	5.2145
10^{-2}	0.7832	-4.0345	3.3194	4.5384	0.1302	-1.6842	1.5237	5.1585
10^{-3}	1.6368	-6.8363	5.381	3.9053	0.1594	-1.7625	1.1558	5.1691
10^{-4}	1.769	-6.8822	4.7254	3.6049	0.1322	-1.5981	0.4971	5.2176
10^{-5}	1.8674	-6.2707	3.196	3.2825	0.1838	-1.7448	0.069	5.2165

Acknowledgments

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