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Model for radiative properties and line transitions of dense hot low Z plasmas using analytical potentials.

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1. Introduction.

ANALOP is a radiative properties calculation code which was developed at first to calculate opacities for medium and high Z plasmas[1]. It uses both an isolated analytical potential [2] and analytical potential with density and temperature effects for atomic data calculations [3], into a relativistic context, within the independent particle model. The opacities were calculated at Local Thermodynamic Equilibrium (LTE) obtaining the ionic abundances by solving the Saha-Boltzmann equation [4].

Actually, this code has been updated to calculate opacities at non-LTE conditions, obtaining the ion abundances by solving the rate equations through the M3R code [5] which has been already coupled to ANALOP code. Moreover, this code has been also improved to allow us to calculate line transition in hot, dense low Z plasmas for hydrogen-like ions [6, 7] and for helium-like ions into a j-j coupling scheme, and including the Stark effect to modelize the line profile [8]. Our interest in the studying of these ions is due to they are the most abundant ions for the conditions appeared in the experiments concerning hot dense plasmas [9, 10].

In the following section these improvements are briefly presented and some relevant results are shown. Finally, in section 3 general remarks and conclusion are presented.

2. ANALOP code improvements.

In this section it has been focused the attention on describing the improvements afore mentioned. Actually, ANALOP code is able to obtain ionic abundances for plasmas in non-LTE. They are obtained by solving the rate equations taking into account the following processes: electron impact ionization and 3-body recombination [11]-[13], radiative recombination [14], electron impact excitation and de-excitation [15], spontaneous decay [16] and dielectronic recombination [17]. The atomic data required to obtain the ionic abundances are provided by solving the Dirac equiations using the analytical potential cited in the previous section. In table 1 the average ionization calculated using several atomic models for some plasma conditions is shown. As it can be seen, a good agreement is founded between the non-LTE average ionizations obtained with analytical potentials and those obtained by using methods based on self-consistent potentials, being the relative error less than two per cent in the worst case.

In table 2, it can be observed the influence of plasma thermodynamic conditions (LTE or non-LTE) over the average ionicity and ionic populations. For instance, for an aluminum plasma at 500 eV and 5×10^{22} cm^{-3} large differences in the H-like ion population are obtained. This fact will yield to relevant differences on the H-like ion line transition intensity as it is shown in figure 1, especially for the Lyman β line. The line profile includes the Stark effect which is the most important width at high density.

Table 1. Average ionization (Z_a) for aluminium plasma at several conditions obtained by using the isolated analytical potential (ISAP) [2], a selfconsitent code (DAVID) [18] and Cowan code [16].

T (eV)	N_e (cm^{-3})	Z_a (ISAP)	Z_a (DAVID)	Z_a (Cowan)
400	10^{22}	12.204	12.197	12.145
	10^{24}	10.489	10.491	10.591
600	10^{22}	12.515	12.489	12.761
	10^{24}	11.585	11.580	11.742

Table 2. Average ionization (Z_a) and ground state populations for H-like Al calculated both in LTE and Non-LTE conditions at several electron densities (T = 500eV).

N_e (cm^{-3})	Z_a LTE	Z_a Non-LTE	Pop(H) LTE	Pop(H) Non-LTE
10^{21}	12.99	12.13	0.0032	0.707
5×10^{22}	12.72	12.41	0.1212	0.348
10^{23}	12.50	12.25	0.187	0.352
2×10^{23}	12.17	12.01	0.238	0.341
5×10^{23}	11.59	11.34	0.217	0.307

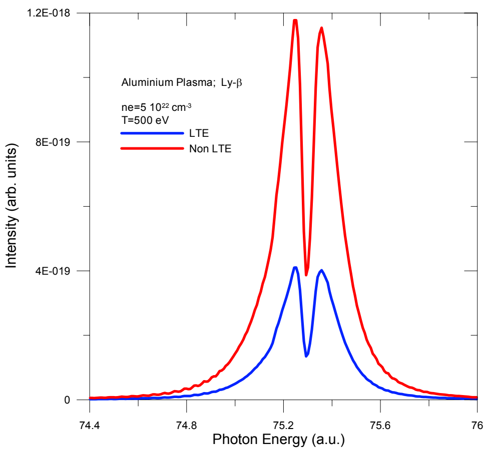

Figure 1. Intensity for the Lyman β line calculated using ISAP both for plasmas in LTE and non-LTE conditions.

With the aim to obtain the He-like ions line transition, it has been obtained the total energies using a total wave function with well defined total angular momentum, which is built up from monoelectronic wave functions determined by using the isolated analytical potential. In table 3, the total energy of several levels for He-like Al is shown, being compared with experimental energies and with the energies obtained from the Cowan code. Relative errors are always less than 0.28% and in general they are less than 0.08%.

Table 3. Total energies (relative to ground state) for He-like Al (ΔE) and errors with respect to experimental total energies [20].

	ΔE (cm-1) ISAP	**ΔE (cm-1) Cowan**	**ΔE (cm-1) Experim.**	**δΔE (%) ISAP**	**δΔE (%) Cowan**
1s2s(3S),J=1	12713385,01	12706177,77	12703460	0,0781	0,0214
1s2p(3P),J=0	12816768,27	12814903,38	12808240	0,0666	0,0520
1s2p(3P),J=1	12845650,52	12814903,38	12809480	0,2824	0,0423
1s2p(3P),J=2	12824851,09	12814903,38	12814580	0,0801	0,0025
1s2s(1S),J=0	12830563,37	12816220,28	12816130	0,1126	0,0007
1s2p(1P),J=1	12882350,03	12892983,70	12891480	-0,0708	0,0117
1s3s(3S),J=1	15032507,98	15027600,66	15020850	0,0776	0,0449
1s3s(1S),J=0	15063045,29	15056998,39	15050610	0,0826	0,0424
1s4s(3S),J=1	15829268,29	15824522,59	15817170	0,0765	0,0465
1s4s(1S),J=0	15841597,96	15836570,38	15829230	0,0781	0,0464

3. General remarks and conclusions.

It has been developed a code (ANALOP) to calculate optical properties in which it can be pointed up the following points:

(1) The atomic properties are obtained by using analitical potentials both for isolated and non isolated ions in ground state and excited configurations which belong to isolectronic sequences from Helium to Uranium.

(2) Because of using analytical potentials instead of self-consistent ones, the computing time is considerably decresased, especially in medium and high Z plasmas.

(3) It provides Rosseland and Planck mean opacities using atomic data obtained into a independent particle model context.

(4) In high density plasmas, it provides the line transition for H-like and He-like ions. For He-like ions the total energies are obtained using a total wave function with well defined total angular momentum, being in good agreement with experimental data.

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