Analysis on the FLYCHK Opacity of Plasmas in a Broad Range of Temperature and Density

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The opacity information is an important property for the numerical research on plasmas. The Planck and Rosseland mean opacities, which are the tendency of a material at a specific density and temperature to absorb and scatter radiation of all frequencies in the matter, are essential inputs of radiation–hydrodynamic simulations. While some opacity projects have provided tabulated data for certain cases, opacity calculations for plasmas in the wide temperature and density range are known to be challenging. Elements and plasma parameters with available and reliable opacities remain limited, and the convergence between different models continues to be an issue.

FLYCHK, which has been widely used as a population kinetic code of plasma spectroscopy, is a suitable code for opacity calculation in this situation. FLYCHK provides population distributions of a reduced set of “hydrogenic” levels so that it characterizes the physical processes occurring in the plasma for a given electron temperature and density fast. Moreover, it includes atomic data of diverse materials (Z=1~79), and thus can provide information on their properties. Due to the simplicity and availability of the FLYCHK code, opacities calculated using this code can be used for plasmas under a wide range of plasma conditions.

In this study, the Planck mean opacity (PMO) and Rosseland mean opacity (RMO) calculations for several elements (e.g. Al, Fe, Cu, Au) are analyzed using the FLYCHK code for the validity and uncertainty of the results. The opacity results of aluminum are compared with the opacities provided by well-known opacity codes, PROPACEOS and ATOMIC for the detailed analysis. As a consequence, we show FLYCHK can provide a reasonable opacity table despite its simplicity.

There are a few caveats in using FLYCHK opacity calculations, nevertheless. First, FLYCHK must be applied carefully for strongly coupled plasmas, and the free–free opacity should be improved. Second, the frequency dependent opacity calculation shows the difference between FLYCHK and ATOMIC calculations due to the absence of $\Delta n = 0$ transitions. This has a large effect on the RMO for the low-photon-energy range. Third, the scattering opacity part should be supplemented to the FLYCHK opacity for the calculation of RMOs. Finally, the PMO is sensitive to the local thermodynamic equilibrium and non-local thermodynamic equilibrium assumptions. In the case of low-density plasmas, the large discrepancy between the average ionization and PMO results for the two modes is observed considerably.

References
[1] M. S. Cho *et al*, J Quant Spectrosc Radiat Transf **257**, 107369 (2020)
[2] M. S. Cho *et al*, J. Korean Phys. Soc. **78**, 1072 (2021)
[3] H. -K. Chung *et al*, High Energy Density Phys. **1**, 1 (2005)

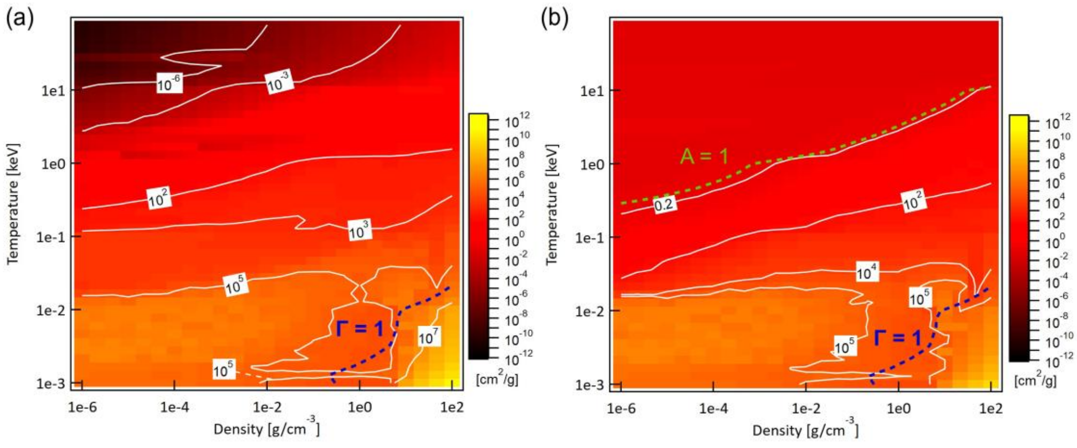

Figure 1. (a) PMO of iron with densities from 10^{-6} to 10^{2} g/cc and temperatures from 10^{-3} to 10^{2} keV calculated in FLYCHK. A blue dotted line means the coupling parameter equal to 1; thus, the strongly coupled regime is in the right downside of the graph. (b) RMO of iron with the same temperature and density range. A green dot-dashed line reveals the scattering and absorption opacity ratio equal to 1.