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Atomic process and radiation transport in laser-produced plasmas

レーザープラズマ中の原子過程と輻射輸送

Atsushi Sunahara
砂原　淳

Institute for Laser Technology
2-6 Yamadaoka Suita Osaka Japan 5654-0871
公益財団法人レーザー技術総合研究所 〒565-0871 吹田市山田丘２－６

Abstract

In simulating the laser-produced plasmas, atomic physics is very important. In order to solve the hydrodynamic motion correctly, we have to conduct the radiation hydrodynamic simulation with the accurate atomic physics. However, the atomic physics in laser-produced plasmas are not easily solved. Here, the non-local thermal equilibrium should be solved frequently. Also, the radiation transport is not easy to be solved. In this talk, I would like to discuss some example of the problem of the atomic physics in laser-produced plasmas.

1. Introduction

In the laser-produced plasmas, radiation process plays an important role on the energy transport. Especially for the applications, such as the interaction of ultra-intense with high-Z materials, the indirect radiation drive implosion in the inertial confinement fusion, the extreme ultraviolet light source, and the laser ablation of metals, high-Z materials are initially heated by the laser, and then the heated and ionized region starts to emit the radiation. A part of emitted photon propagating into the material can be easily absorbed in the material. This energy deposition by radiation can heat the material above the melting temperature and drive the motion of the material.

2. Non-LTE

In the absorption of photon, there are three transitions can occur; free-free transition such as inverse-bremsstrahlung, bound-free such as photo-ionization, bound-bound such as the photo-excitation, respectively. Competition of photon process and collisional one determines the population density. If collisional process is dominant, the plasma condition is in the local thermal equilibrium (LTE). In LTE, the electron population density can be obtained by Boltzmann distribution. However, as the plasma density decreases and plasma temperature increases, the collisionality of the electron in the plasma decreases compared to the photon process. In this region collisional radiative (CR) model is adopted to obtain the electron population density. In CR model, the rate equation considering both collisional and radiation processes are solved. Therefore, the accuracy of the rate coefficients of those transitions can significantly affect the numerical solution of the electron population density. Resultantly the ionization degree that is very important parameter for the atomic physics and electron and ion thermal conduction in the plasma, can be affected by the accuracy of the rate coefficients. In this talk, I will show some radiation process in laser-produced plasmas. In simulating the hydrodynamic motion of the laser-produced high-Z materials correctly, accurate coefficients of atomic physics, such as the rate coefficients are required. Furthermore, electron transport is coupled with the radiation transport. In which the nonlocal transport of electron should be taken into account, because the velocity distribution function of electrons in laser-produced plasmas is not necessary Maxwell distribution function.

3. Radiation transport

Radiation transport is also very important issue in calculating the dynamics of the laser-produced plasmas. Due to the radiation transport, internal energy at different position can interact and couple. In which, the accuracy of calculating the radiation transport is important as well as the accuracy of emissivity and opacity at each position. Radiation transport can be solved by many schemes. However, the radiation transfer equation is equivalent to six-dimensional Boltzmann equation and it is difficult to be solved in the multi-dimensional. In order to combine the calculation of multi-dimensional radiation transport and hydrodynamic simulation, the moment method has been widely used. In this moment method, the radiation energy density E, radiation flux F, and higher order moment of photon spectral intensity such as photon pressure P= (f E) are used as independent variables. Here f is the Eddington tensor. Then the moment equations are described as;

$$\frac{\partial E_\nu}{\partial t} + \nabla \cdot \mathbf{F}_\nu = 4\pi\eta_\nu - c\chi_\nu E_\nu \quad (1)$$

$$\frac{\partial \mathbf{F}_\nu}{\partial t} + \nabla \cdot (c^2 \mathbf{f}_\nu E_\nu) = -c\chi_\nu \mathbf{F}_\nu \quad (2)$$

here, zeroth and first-order moment equations are shown. Assuming radiation pressure P to be (f E), two equations can be solved because the independent variables are only E and F. η is the emissivity and χ is absorption coefficient for photon energy h ν. Here, h is the Planck constant and ν is the oscillation frequency of photon. Full set of equation (1) and (2) are solved by M-1 method[1]. In the talk, the solution by M-1 method is compared with other method such as the flux-limited diffusion approximation(FLD). M-1 method shows better quality of the radiation transport. However, computational time and numerical stability are better for the FLD method.

References

[1] M. Gonz´alez., E. Audit, and P. Huyunh, A&A 464（2007）429-435.