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X-ray emission from inner-shell ionization of Ne-like ions

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Abstract

We study the X-ray emission from the inner-shell states of S and Fe ions excited by black-body radiation. At a low temperature, the X-ray intensities from inner-shell excited states are smaller than that of Heα. However, at high temperature, both are almost the same. From this trend, we may understand the temperature of the black-body radiation. This may be applied to the analysis of the X-ray emission from X-ray binary stars. Namely, the atomic data along with the inner-shell ionization processes may be useful for astrophysics as well as inner-shell ionization X-ray lasers.

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1. Introduction

The inner-shell ionization processes have been considered to be useful methods for X-ray laser emission [1–7]. However, there has been yet no experimental demonstration of X-ray lasing using inner-shell processes, even though several models have been proposed [1–7]. Interesting atomic processes have been noticed by Moribayashi et al. [4], leading to a model for a hollow atom X-ray laser. The hollow atoms are produced through ultrafast inner-shell ionization processes, which arise from the interaction of an atom or an ion with a high intensity X-ray source. They also have proposed that the Larmor X-rays [8] may be good as an X-ray excitation source [4,5]. Kim and his co-workers [6,7] have proposed another new physical scheme for femto-second X-ray lasers, in which the upper lasing level is pumped by fast electron impact [6] or X-ray photons [7] and the lower lasing level is depopulated via Coster–Kronig transitions. Such processes may also be important in astrophysics because the interaction of atoms or ions with some high brightness X-ray sources takes place in the universe such as X-ray binary stars. Recently, the 'photo-ionized plasmas' have been paid attention to in X-ray binary stars such as Cyg X-3 [9,10] where a lot of atoms or ions transfer from a star to a black hole via accretion by gravitation because the star is located near the black hole. On the other hand, high intensity

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X-rays are emitted from the black hole. After ions are inner-shell photo-ionized by X-rays, the characteristic X-rays may be emitted from inner-shell excited states of ions. From these X-rays, we may understand the ionized states of stars and the temperature of the X-rays emitted from the black hole. Until now, only the Lyα, Heα and Kα X-rays of heavy ions such as Si, S and Fe have been discussed because of the X-ray detector with a low resolving power in the satellites 'Chandra' or 'Asca' [9,10]. We expect that the X-ray emission from inner-shell excited states becomes important for the analysis of the mechanism of the X-ray binary stars because the satellite 'Astro-E2' will be launched in future, which has an X-ray detector with a higher resolving power [11]. In this paper, we calculate the X-ray spectra emitted from inner-shell excited states of S and Fe ions in black-body radiation. We show that our calculations may be useful for astrophysics as well as intensity laser physics [12,13].

2. Atomic processes

Illustrated in Fig. 1 are schematic atomic processes considered here. The initial state of ions is assumed to be the ground state of Ne-like ion. We consider photo-ionization, radiative transition and auto-ionization processes. We have calculated their atomic data of Ne-like ions using Cowan's code [14]. For the other ions, we employ the empirical formula given in [4,15]. By using these atomic data, the rates of change of concentrations of the various atomic states as illustrated in Fig. 1 may be governed by the following equations:

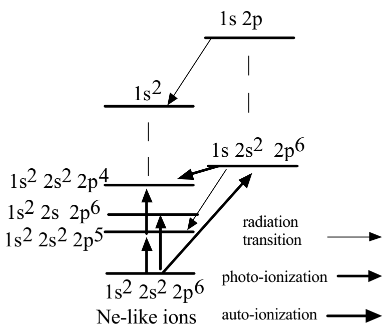


Fig. 1. Atomic processes in the X-ray emission in the radiation field.

$$\frac{dN_k}{dt} = -\alpha_k N_k + \sum_{m(>k)} \beta_{mk} N_m, \tag{1}$$

where N_k, α_k and β_{mk} are the population, decay constant in the kth state, and the transition rate from the m state to k state, respectively. The photon number is given by

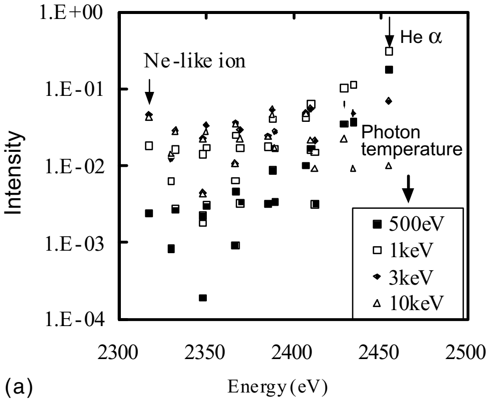
$$P_k = \int_0^\infty N_k Ar \, dt, \tag{2}$$

where Ar is the radiative transition probability from the inner-shell excited state.

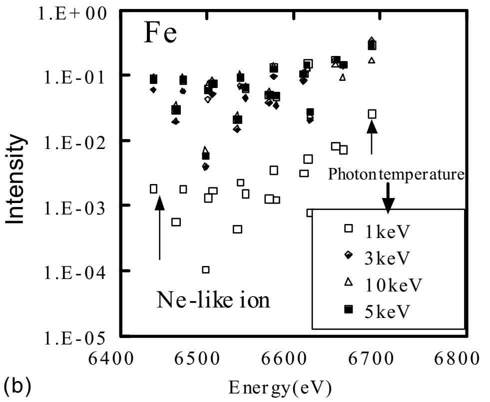
3. Results and discussions

The X-ray intensities emitted from the inner-shell excited states may give important information to astrophysics as mentioned in Section 1. Here we show our results of the X-ray intensities emitted from inner-shell states excited by black-body radiation.

Figs. 2(a) and (b) show X-ray intensities as a function of the averaged X-ray energies emitted from inner-shell excited states and He-like ions of S and Fe ions, respectively. The marks in the figures correspond to the temperatures (T_B) of the black body radiation. In Fig. 2(a), the X-ray intensities from the inner-shell excited states of the S ions are much smaller than that from the He-like ion (the largest photon energy) at $T_B < 3$ keV. On the other hand, at $T_B \geqslant 3$ keV, both intensities become almost the same. This comes from the fact that the inner-shell photo-ionization rates become faster, that is, they are comparable to or more than any rates such as auto-ionization, radiative transition, outer-shell ionization [1]. In Fig. 2(b), almost the same trend as Fig. 2(a) is found. Namely, the X-ray emission from the He-like ion dominates at low T_B while that from the inner-shell excited states is comparable to that from the He-like ion at high T_B. The X-ray intensities are larger than those



(a)



(b)

Fig. 2. X-ray intensity versus photon energy (eV) emitted from the inner-shell excited states for various photon temperatures of the black body radiation: (a) S ions, (b) Fe ions. The correspondence between the photon temperatures and symbols is shown in the boxes. The X-ray emission from inner-shell excited states of Ne-like (left side) and Heα (right side) is marked.

given in Fig. 2(a), which is due to the fact that branching ratio between the radiative transition probability and autoionization rate (Aa) from the inner-shell excited states, that is, $Ar/(Aa + Ar)$, becomes larger. From Fig. 2, we propose that the X-ray spectra from the inner-shell excited states inform us on the temperature of the black-body radiation. This may become useful for astrophysics because the satellite 'Astro-E2' will be able to measure these X-rays emitted from X-ray binary stars. In this paper, we have used the atomic data derived from the empirical formula and the averaged photon energies as mentioned before. For the comparison with the real spectra, more detailed atomic data are required.

4. Conclusions

We study the X-ray emission from Ne-like S and Fe ions to apply for astrophysics. We calculate the X-ray intensities from the inner-shell excited states of Ne-like to Li-like ions and Heα. The intensity of Heα is much larger than those of the inner-shell excited states at a low temperature of less than 3 keV. On the other hand, at the temperature of more than 3 keV, the former are almost the same as the latter. This trend may inform us of the temperature of X-rays emitted from an X-ray binary stars. For the analysis of the X-ray binary stars, more detailed atomic data may be required.

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