Development of collisional-radiative model for lower charge state of oxygen ions in GAMMA 10

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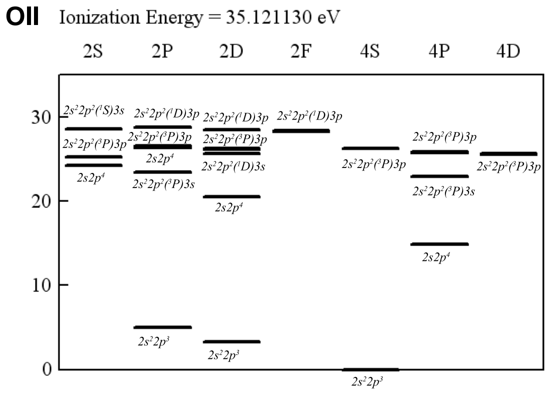
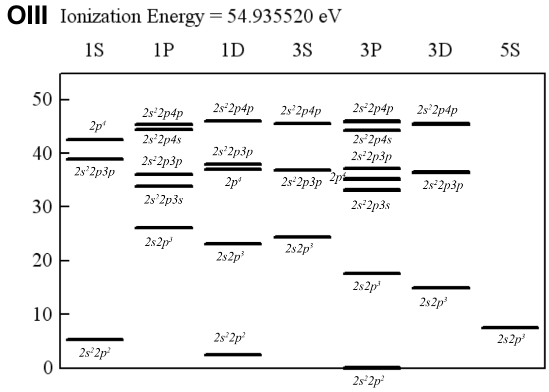
1. Introduction. In fusion plasmas, behavior of impurities is one of the important issues because of its strong relation to a radiation loss and a plasma-wall interaction. Impurity line spectra have a lot of important information of a plasma, such as an impurity density and temperature, an electron density and temperature, rotation velocities of ions and an electric field, etc. in a plasma. Then spectroscopic measurements of various wavelength regions (soft X-ray, vacuum ultraviolet, ultraviolet and visible) are carried out in various fusion devices. The emission intensity from an impurity ion is proportional to the population density of the excited state of the impurity ion. The population density of the excited state depends on the electron density, the electron temperature and the impurity density. The relation of each parameter is given by a collisional-radiative model (CR-model). The CR-model is used in the region between corona-equilibrium (low density) and thermal-equilibrium (high density). In this region, both of the collisional process and the radiation process are important. In the GAMMA 10 tandem mirror, space and time resolved spectra are observed by using absolutely calibrated ultraviolet/visible spectrometer, vacuum ultraviolet spectrometer and soft X-ray spectrometer. Line emissions from CII, CIII, OII, OIII, OIV and OV are mainly observed in GAMMA 10 [1-3]. The CR-models for CII and CIII have been developed [4]. We have been evaluated density profiles of carbon atom and ions [5]. There was the CR-model calculation code for OV. However CR-models for lower charge state of oxygen ions have not been developed. Then, we started to construct the CR-models for the lower charge state of oxygen ions. In GAMMA 10, emissions from oxygen ions have the highest intensity. Therefore, measurements of oxygen ion spectra from lower charge state to higher charge state are very useful for estimation of plasma parameters and for evaluating impurity behavior in GAMMA 10.

2. Developments and Results. In order to study impurity behavior in detail in the GAMMA 10 tandem mirror, we started to develop a CR-model calculation code for lower charge state of oxygen ions, OII, OIII and OIV. A lot of atomic processes such as radiative transition, electron impact excitation, de-excitation and ionization, three body recombination, photo





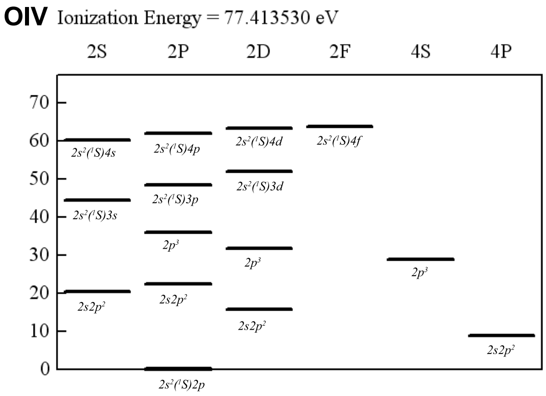
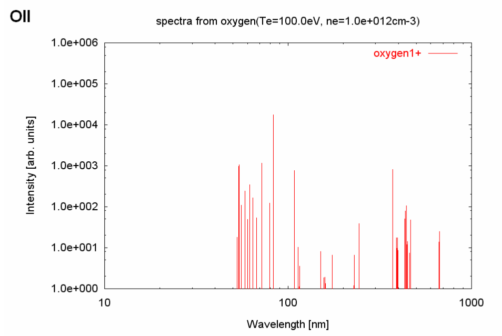


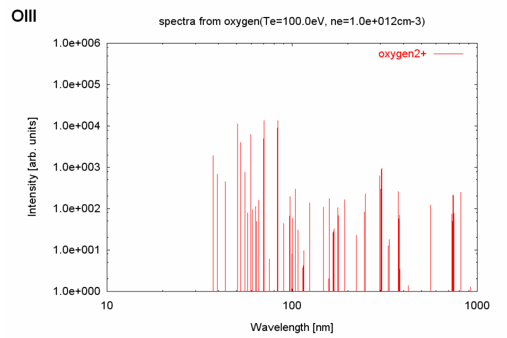
Figure 1 Energy level diagrams of OII, OIII and OIV. Those levels are included in the new model

ionization, radiative recombination, auto ionization, dielectric recombination and also ion collision processes and charge exchange processes are needed to develop the CR-model completely. However ionizing plasma components are mainly important in the GAMMA 10 tandem mirror. Then we included radiative transition, electron impact excitation, de-excitation and ionization processes into our new model. Energy levels are also important information. We obtained energy levels and transition probabilities from web site of NIST [6]. In order to calculate lots of collision cross sections easily, flexible atomic code (FAC) were developed by M. F. Gu [7]. FAC is free software and we can use it on Linux. We calculated the electron impact excitation and ionization cross sections with FAC. We integrated the cross sections with Maxwell-distribution in order to obtain the rate coefficients. Then we obtained the electron impact de-excitation rate coefficient, which is expressed as

$$C_{ij} = \frac{g_j}{g_i} e^{-E_{ij}/k_B T} C_{ji}$$

where, C, g, E_{ij} and T is the rate coefficient, the statistical weight, the transition energy and the electron temperature, respectively. Figure 1 shows the energy levels those were included into our new model. The excited states those have low excitation energy from ground state are important because our plasma condition is in the ionizing plasma. We developed the





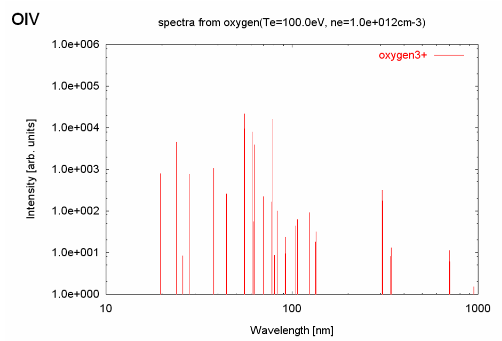


Figure 2 Emission intensity from OII, OIII and OIV calculated by our new models.

CR-model calculation code for each oxygen ions separately. Figure 2 shows emission intensity versus wavelength calculated by the new models in the condition of the electron density $1\times10^{12}cm^{-3}$ and the electron temperature 100 eV. Verification of our new model is important. We could not compare our CR-model code and a reliable CR-model code because there were no verified codes. However, there was the CR-model code of CII which had been used in a lot of cases of plasma diagnostics [5]. Then we developed the CR-model of CII by the same procedure of OIV in order to compare the calculation results of our code and existing code. Figure 3 shows the calculation results of population ratios of CII by each calculation code. In the existing code, fine structure of the level is not completely separated. While in our new code, all fine structure is treated separately. Then we compared same averaged each fine structure levels weighed with statistical weight. Index numbers of horizontal axis are shown in Table 1. In Fig. 3, open circles show our new code and closed circles show the existing one. In this comparison, the result of our new code is almost comparable to the existing one with the exception of the level $2s^2 4f$ (^2F). The reason of incomparable result is come from the difference of the electron impact excitation rate coefficients from ground state to $2s^2 4f$ (^2F). In the existing code, lots of those rate coefficients were obtained from calculation results of Itikawa et al [8]. However, the rate coefficient from ground state to $2s^2 4f$ (^2F) was obtained from Mewe's formula [9]. Then we have to verify which one is more reliable to explain the results of experiments. Excepting above, we could obtain almost comparable results to the existing one. Then we will be able to obtain the lower charged oxygen ion density profiles by comparing the CR-model calculation and the spectral measurement in the GAMMA 10 tandem mirror. Further more, we plan to include some recombination processes and ion collision processes in order to modify our new models.

3. Summary. In order to evaluate impurity behavior in the GAMMA 10 tandem mirror, we developed a CR-model calculation code for lower charge state of oxygen ions. We used FAC and the database of web site of NIST. We calculated the population ratio and radiation rate for OII, OIII and OIV. In order to verify our new model, we developed the CR-model code of CII and compared the new code and the existing one. We could obtain the comparable results to the existing code with the exception of $2s^2 4f$ (^2F).

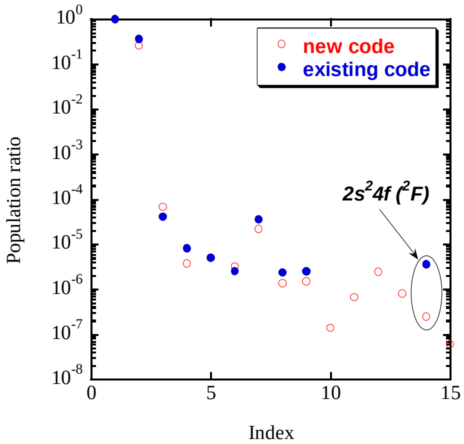


Figure 3 Population ratio of CII calculated by our new code and the existing code.

Index	Configuration	Term
1	2p1	2P*
2	2s1 2p2	4P
3	2s1 2p2	2D
4	2s1 2p2	2S
5	2s1 2p2	2P
6	3s1	2S
7	3p1	2P*
8	2p3	4S*
9	3d1	2D
10	4s1	2S
11	2p3	2D*
12	4p1	2P*
13	4d1	2D
14	4f1	2F*
15	2p3	2P*

Table 1 Index number and configurations. of CII

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References. [1] M. Yoshikawa, et al., Trans. Fusion. Technol., 39, 289(2001) [2] M. Yoshikawa, et al., J. Plasma Fusion Res. SERIES, Vol.6 685(2004) [3] T. Kobayashi, et al., Rev. Sci. Instrum., 75, 4121(2004) [4] T. Kato, et al., Fusion Eng. Des., 34-35, 789(1997) [5] T. Kobayashi, et al., to be printed in J. Plasma Fusion Res. SERIES, Vol. 7 [6] NIST: atomic spectra database (http://physics.nist.gov/PhysRefData/ASD/index.html) [7] M. F. Gu, ApJ., 582, 1241(2003) [8] Y. Itikawa, et al., Atomic Data and Nuclear Data Tables, 33, 149 (1985) [9] R. Mewe, Astron. Astrophys., 20. 215 (1972)