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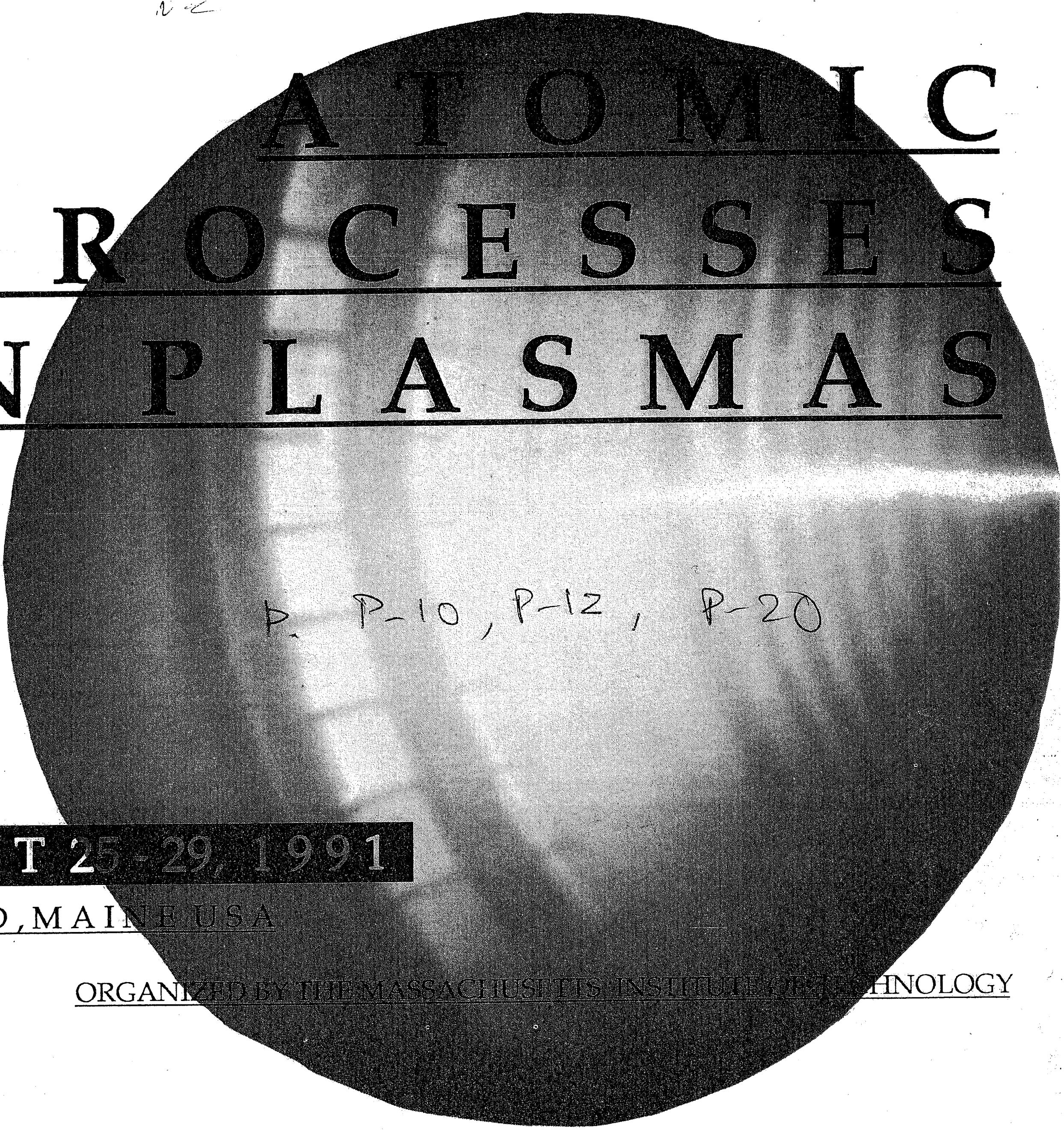

# ATOMIC PROCESSES IN PLASMAS

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## PROGRAM and ABSTRACTS

# I-15 Line Ratios in $Ti^{+18}$ in the JIPPT-II-U Tokamak Plasma

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In general, line ratios observed in high temperature-low density magnetically confined (ohmically-heated) plasmas in tokamaks can be explained by the collisional-radiative model: electron-impact excitation of ions to higher levels and their subsequent radiative decay to lower levels. In some experiments however discrepancies[1] between the collision-radiative model predictions and experiment have been obseved: for instance in the JIPPT-II-U tokamak in Nagoya, when the plasma is heated by ion-cyclotron radio frequency (ICRF) pulse in addition to the ohmic heating, the line ratios

$$R^{*}=I(2s2p\ {}^3P_1 \rightarrow 2s^2\ {}^1S_0)/I(2s2p\ {}^1P_1 \rightarrow 2s^2\ {}^1S_0) \qquad (1)$$

and

$$R=I(2p^2\ {}^3P_2 \rightarrow 2s2p\ {}^3P_2)/I(2s2p\ {}^1P_1 \rightarrow 2s^2\ {}^1S_0) \qquad (2)$$

in $Ti^{+18}$ calculated in the collisional-radiative model were nearly seven times lower than the observed value.[1] The inclusion[2] of n=3 and 4 levels in the collisional-radiative model did not improve the agreement with the observations. Since it has also been shown[2] that resonances are not important for highly ionized systems the discrepancy should not originate in the collision rates used in the model. The ratios $R^*$ and R increase if inner-shell ionization of $(1s^22s^22p)^2P$ state of $Ti^{+17}$ to $(1s^22s2p)^{1,3}P$ states of $Ti^{+18}$ is included[2] in the equilibrium equations to calculate the level populations and intensity ratios. In order to match[1] the experimental values, the fractional abundance of $Ti^{+17}/Ti^{+18}$ has to be between 5 and 10. This appears to be a strong non-equilibrium situation. However, there is another process which could contribute to the populations of $(1s^22s2p)^{1,3}P$ states of $Ti^{+18}$, and the fractional abundance mentioned above need not be very high. This is the radiative-recombination process:

$$e + 1s^22s\ {}^2S(Ti^{+19}) \rightarrow h\nu + 1s^22s2p\ {}^{1,3}P(Ti^{+18}). \qquad (3)$$

On the other hand, there could be a radiative recombination of $Ti^{+18}$ to $Ti^{+17}$:

$$e + 1s^22s2p\ {}^{1,3}P(Ti^{+18}) \rightarrow h\nu + 1s^22s^22p\ {}^2P(Ti^{+17})\ , \qquad (4)$$

which would result in a loss of population from $^{1,3}P$ states of $Ti^{+18}$. These two processes should also be included in addition to

$$e + 1s^22s^22p\ {}^2P(Ti^{+17}) \rightarrow 1s^22s2p\ {}^{1,3}P(Ti^{+18}) + e + e, \qquad (5)$$

in the equilibrium equations in order to obtain level populations.

The rate coefficients for the first two processes depend on the photoionization cross sections, which have been calculated in the single configuration Hartree-Fock approximation.[3] The cross section, $\sigma_R$, for radiative recombination is related to photoionization cross section $\sigma$

through the principle of detailed balance as

$$\sigma_R = (\omega/2\omega_+)(h\nu/mc^2)(h\nu/\epsilon)\sigma \qquad (6)$$

where

$\omega$= weight factor of recombined ion and $\omega_+$= weight factor of recombining ion. The recombination rate coefficients averaged over the Maxwellian distribution are calculated using $\sigma_R$ in the temperature corresponding to energy range 300 to 3000 eV, the highest teperature in the tokamak.

Atomic data for $Ti^{+18}$ have been calculated[4] with the inculsion of $2s^2$, 2s2p, $2p^2$, 2s3s, 2s3p, 2s3d, 2s4s, 2s4p, and 2s4d configurations, giving rise to 30 levels. Energy levels, transition rates and collision strengths have been calculated using the University College programs.[5,6] The collision strengths are calculated in the distorted wave approximation.[6] The rate coefficients for inner-shell ionization of $(1s^2 2s^2 2p)\,^2P$ state in $Ti^{+17}$ have been calculated using the formulae given by Arnaud and Rottenflug.[7]

We calculated the intensity ratios $R^*$ and R by including the inner-shell and radiative recombination rates in the equilibrium equations. The fractional abundance $Ti^{+19}/Ti^{+18}$ has been taken equal to one and the electron density $n_e$ has been taken as $2\times10^{13}$ $cm^{-3}$, a typical density in the tokamak. The intensity ratios $R^*$ and R were calculated with and without radiative recombination rates, intensity is defined as $N_j$ $A_{ji}$ for a transition j to i. The two sets of values of $R^*$ and R show almost no difference between them indicating that the radiative recombination contribution has a negligible effect on the observed line ratios. We found that in order to obtain the experimental values of $R^*$ and R, the fractional abundance $Ti^{+17}/Ti^{+18}$ has to be between 5 and 10, the same conclusion arrived at without the inclusion of radiative rates. We could have taken the fractional abundance $Ti^{+19}/Ti^{+18}$ different than one and such as to give the observed ratios $R^*$ and R without having a high abundance ratio $Ti^{+17}/Ti^{+18}$. But then, it would still be a non-equilibrium situation.

Another important radiative process, dielectronic recombination, should be of much interest to look into to find its effect on the line ratios. In general, the dielectronic recombination cross sections are larger than those of radiative recombination and at higer temperatures they could dominate over the direct radiative processes.

In summary, we have shown that the radiative recombination rates are not important in order to explain the observed line ratios when ICRF pulse heating is present in addition to the ohmic heating. There could be other processes taking place. We hope that this investigation will provide motivation to look beyond what we have considered to explain the non-equilibrium situation mentioned above.

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