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Research Note

The influence of ion-atom radiative collisions on the continuous optical spectra in helium-rich DB white-dwarf atmospheres

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Abstract. We investigate the influence of radiative processes due to $He^+(1s)$-$He(1s^2)$ collisions on the continuous optical spectrum of the helium-rich DB white-dwarf atmospheres. We show that these ion-atom collision processes are important in certain layers of the studied white dwarf atmosphere, and that the corresponding contributions to the optical depth and continuous opacity are not negligible.

Key words: White dwarfs – radiation mechanisms: thermal – atomic processes – stars: atmospheres

1. Introduction

The influence of $H^+ + H(1s)$ radiative processes on the continuous spectra of low temperature solar-atmosphere layers where the H(1s) + e radiative processes play the main role has been studied in Mihajlov et al. (1993, 1994). It was shown that $H^+ + H(1s)$ radiative processes are of importance for such layers, in spite of the fact that the main H(1s) + e radiative processes include the very improtant process of H^- stable ion photo-creation and photo-dissociation. This suggests that radiative $He^+(1s) + He(1s^2)$ processes may be very important for low-temperature ($T \lesssim 20\,000$ K) atmospheric layers in helium-rich stars, where the influence of the competing $He^+(1s^2)$ + e radiative process is less significant since a stable negative atom ion does not exist for helium (Massey 1976).

We will consider the following ion-atom radiative processes

$$He^+(1s) + He^+(1s^2) \Leftrightarrow \epsilon_\lambda + He_2^+ , \qquad (1a)$$

$$He^+(1s) + He^+(1s^2) \Leftrightarrow \epsilon_\lambda + \begin{cases} He^+(1s) + He^+(1s^2) \\ He^+(1s^2) + He^+(1s) \end{cases} \qquad (1b)$$

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where He_2^+ is the molecular ion in the electronic ground state $(1\sum_u^+)$, and $\epsilon_\lambda = 2\pi\hbar c/\lambda$ – the energy of a photon with wavelength λ. In this paper we will show the importance of these processes for the DB white-dwarf atmosphere optical continuous spectra, on an example from Koester (1980). Consequently, we will investigate the contribution of processes (1) to the optical continuous spectra in comparison with the contribution of the following electron-atom and electron-ion radiative processes

$$He(1s^2) + e \Leftrightarrow \epsilon_\lambda + He(1s^2) + e ; \qquad (2)$$

$$A^+ + e \Leftrightarrow \epsilon_\lambda + \begin{cases} A^+ + e \\ A^* \end{cases} \qquad (3)$$

which are of importance for the DB white dwarf atmosphere plasma composition (Bues 1970). Here A^+ denotes helium, hydrogen or metallic atomic ion and A^* is the corresponding atom in an excited state.

2. Theory

The contributions of processes (1a), (1b), (2), (3) to the plasma absorption and emission continuous spectra is characterized by the spectral absorption coefficients $\kappa_{ia}^{(a)}$, $\kappa_{ia}^{(b)}$, κ_{ea}^{ff} κ_{ei} and the spectral emissivities $\varepsilon_{ia}^{(a)}$, $\varepsilon_{ia}^{(b)}$ ε_{ea}^{ff}, ε_{ei} where the index ff emphasizes that e – $He(1s^2)$ radiative processes are consequences of free-free electron transitions only. In the case of processes (1) we will use also quantities $\kappa_{ia}^{(ab)} = \kappa_{ia}^{(a)} + \kappa_{ia}^{(b)}$ and $\varepsilon_{ia}^{(ab)} = \varepsilon_{ia}^{(a)} + \varepsilon_{ia}^{(b)}$ which take into account the contribution of processes (1a) and (1b) together.

We will determine the relative contribution of the processes (1a,b) in comparison with electron-atom processes (2) and electron-ion processes (3) using the quantities

$$F_{ea}^{ff} = \frac{\varepsilon_{ia}^{(ab)}}{\varepsilon_{ea}^{ff}} = \frac{\kappa_{ia}^{(ab)}}{\kappa_{ea}^{ff}} , \quad F_{ei} = \frac{\varepsilon_{ia}^{(ab)}}{\varepsilon_{ei}} . \qquad (4)$$

In LTE, $\kappa_{ia}^{(ab)}/\kappa_{ei} = \varepsilon_{ia}^{(ab)}/\varepsilon_{ei}$. However, according to Koester (1980) the low-temperature layers of DB white dwarf atmosphere have relatively small optical depths. Consequently, considerable deviations of the excited atomic states (A^*) populations from LTE populations should exist. It means that the use of the ratio $\kappa_{ia}^{(ab)}/\kappa_{ei}$ requires complete calculations of the excited atomic state population distribution function. For that reason we use here the ratio $\varepsilon_{ia}^{(ab)}/\varepsilon_{ei}$ where ε_{ei} depends on the densities of only several atomic ions.

The spectral coefficients $\kappa_{ia}^{(ab)}$ and $\varepsilon_{ia}^{(ab)}$ take the form

$$\kappa_{ia}^{(ab)}(\lambda, T) = K_{ia}^{(ab)}(\lambda, T) N(He^+) N(He) ,$$
$$\varepsilon_{ia}^{(ab)}(\lambda, T) = S_{ia}^{(ab)}(\lambda, T) N(He^+) N(He) , \quad (5)$$

$$\frac{\kappa_{ia}^{(ab)}(\lambda, T)}{\varepsilon_{ia}^{(ab)}(\lambda, T)} = \frac{K_{ia}^{(ab)}(\lambda, T)}{S_{ia}^{(ab)}(\lambda, T)} = \frac{2\pi^3 \hbar^4 c^3}{\epsilon_\lambda^5} \cdot \exp\left(\frac{\epsilon_\lambda}{kT}\right) \cdot \left[1 - \exp\left(-\frac{\epsilon_\lambda}{kT}\right)\right], \quad (6)$$

where $N(He^+)$ and $N(He)$ are the He^+ and He densities, and the factor $[1 - \exp(-\epsilon_\lambda/kT)]$ describes the influence of the stimulated emission on the total absorption. The validity conditions of the Eqs. (4, 5) have been discussed in Mihajlov & Dimitrijević (1986) and (1992).

In our calculations we take $F_{ea}^{ff} = \kappa_{ia}^{(ab)}/\kappa_{ea}^{ff}$. Consequently, we will determine the quantities F_{ea}^{ff} and F_{ei} from the spectral coefficients κ_{ea}^{ff} and ε_{ei}, where

$$\kappa_{ea}^{ff}(\lambda, T) = K_{ea}^{ff}(\lambda, T) N(He) N_e ,$$
$$\varepsilon_{ei}(\lambda, T) = \sum_A S_{ei}^A(\lambda, T) N(A^+) N_e . \quad (7)$$

Here, N_e and $N(A^+)$ denote the free electron and A^+ ion densities, respectively.

In Eqs. (5) and (6) we use semiclassical values of $K_{ia}^{(ab)}(\lambda, T)$ from Mihajlov & Dimitrijević (1992), where these coefficients are given in analytical and tabular form. Values of $S_{ia}^{(ab)}(\lambda, T)$ were determined from Eq. (6).

In Eq. (7) we use tabulated values of $K_{ea}^{ff}(\lambda, T)$ from Bell et al. (1982). Values of $S_{ei}^A(\lambda, T)$ were calculated with the help of a quasiclassical analytical expression from Menzel (1962) and Sobelman (1979).

3. Results and discussion

The calculations of quantities F_{ea}^{ff} and F_{ei} from Eqs. (4–7), have been performed for DB white dwarf atmospheres in the case $\log g = 8$ and $T_{eff} = 12000$ K. The plasma temperature (7942 K $\leq T \leq$ 21039 K), Rosseland optical depth ($-5.60 \leq \log\tau \leq 2.75$) and other relevant data from Table 1 in Koester (1980) have been used. In the considered $\log\tau$ range the temperature T monotonically decreases from 8119 K up to 7942 K for $\log\tau \leq -3.60$ and after that monotonically increases up to 21 039 K for $\log\tau \leq 2.75$.

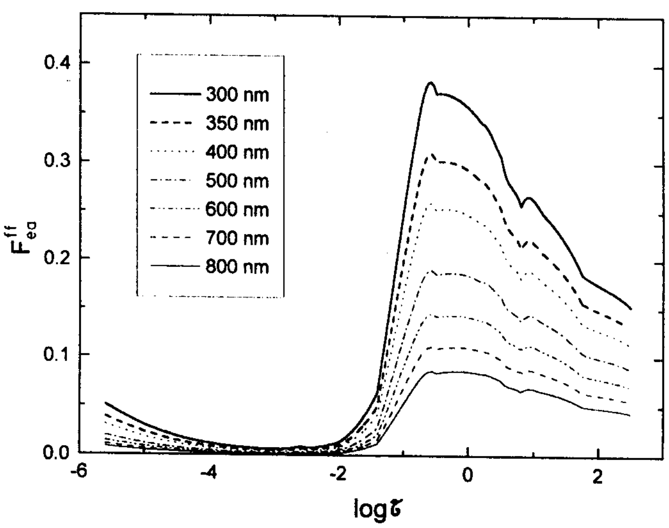

Fig. 1. The behavior of the parameter $F_{ea}^{ff}(\lambda, T)$ within the 300 nm $\leq \lambda \leq$ 800 nm range, as a function of Rosseland optical depth

The comparison of the contribution of processes (1) and (2) is presented in Fig. 1 where the behavior of the quantity $F_{ea}^{ff}(\lambda, T)$ for 300 nm$\leq \lambda \leq$ 800 nm is shown. We can see that $F_{ea}^{ff}(\lambda, T)$ increases fast for $-2.0 < \log\tau < -1.0$, reaches a maximum and after that decreases slowly with further increase of $\log\tau$. As a consequence there exists a relatively large region (with $-1.5 < \log\tau$) where the quantity $F_{ea}^{ff}(\lambda, T)$ is within the range 0.05–0.40, for the considered range of wavelengths.

The comparison of processes (1) and (3) is presented in Fig. 2 where the behavior of the quantity $F_{ei}(\lambda, T)$, for the same λ range, is shown. We can see that for $-2.5 < \log\tau < 1.0$, $F_{ei}(\lambda, T)$ has a maximum, which is more pronounced than the maximum of $F_{ea}^{ff}(\lambda, T)$. This maximum occurs around $\log\tau = -1.0$ where the quantity $F_{ei}(\lambda, T)$ is within the range 5–40, i.e. two orders of magnitude larger than $F_{ea}^{ff}(\lambda, T)$. Outside the range, the quantity $F_{ei}(\lambda, T)$ decreases more sharply than $F_{ea}^{ff}(\lambda, T)$. It shows that the electron-ion process (3) determines the border of the $\log\tau$ range where the processes (1) are of interest. Namely, Fig. 2 shows that this border is inside of the considered $\log\tau$ region for all the λ considered. Moreover, the behaviour of the quantities F_{ea}^{ff} and F_{ei} as functions of $\log\tau$ is such that we can expect the electron-ion radiative processes to dominate in comparison with the electron-atom and ion-atom radiative processes outside of the considered $\log\tau \leq 2.75$ range.

Figure 1 shows the importance of the ion-atom radiative processes (1) and the necessity to take them into account when calculating the optical characteristics of DB white dwarf atmosphere. It is a direct consequence of the fact that a stable negative helium atomic ion does not exist. Conversely, we have seen that in the case of the solar atmosphere (see Mihajlov et al. 1993, 1994), where hydrogen negative stable atomic ion exist, the relative contribution of ion-atom radiative processes in compar-

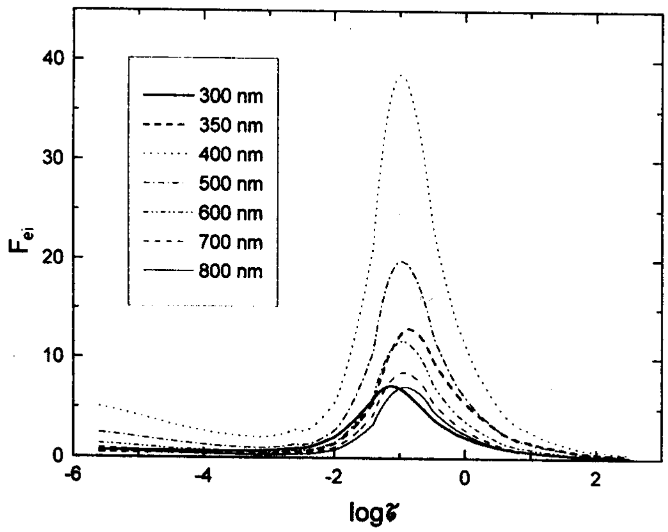

Fig. 2. The behavior of parameter $F_{ei}(\lambda, T)$, within the $300\,\mathrm{nm} \leq \lambda \leq 800\,\mathrm{nm}$ range, as a function of Rosseland optical depth. The strong change between $F_{ei}(\lambda = 300\,\mathrm{nm})$ and $F_{ei}(\lambda = 350\,\mathrm{nm})$ is real, since between these λ are two thresholds of helium-photorecombination continuums with the principal quantum number 2

ison with electron-atom radiative processes is only within the 0.05–0.15 range.

We have estimated also the corresponding increase of the optical depth $\Delta\tau$ of the considered atmosphere layers and the change of the emergent intensity (see e.g. Mihalas 1978). The ratio $\Delta\tau/\tau$ for $\lambda = 500$ nm increases from about 0.0034 to about 0.1711 for $-2.00 \leq \log\tau \leq 0.30$ and after that decreases (to 0.0721 for $\log\tau \leq 2.75$). The calculations of the emergent intensity have been performed for radial rays. For the same λ we have that processes (1a,b) caused a decrease of the emergent intensity, for the considered $\log\tau \leq 2.75$ range by about 16 per cent.

In agreement with Mihajlov & Dimitrijević (1992), we have shown that in the considered case the radiative charge-exchange processes (1b) are more significant than the photoassociation/photodissociation processes (1a). Our calculations show that the decrease of the emergent intensity, for $\lambda = 500$ nm, is around 14 per cent when processes (1a) have not been taken into account.

4. Conclusion

It has been shown that the radiative ion-atom processes (1), not taken into account up to now in DB white dwarf research from the spectroscopical point of view, are of importance in the $300\,\mathrm{nm} \leq \lambda \leq 800\,\mathrm{nm}$ range. In low temperature ($8000\,\mathrm{K} \lesssim T \lesssim 20\,000\,\mathrm{K}$) layers the contribution of processes (1) to the optical continuous spectra is more important than the contribution of electron-ion processes (3) and is comparable with the contribution of electron-atom processes (2). Consequently, the ion-atom processes (1) considered here should be taken into account for calculations of the characteristics for low-temperature ($T \lesssim 20\,000$ K) atmospheric layers in helium-rich stars

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