The quasi-molecular absorption bands in UV region caused by the non-symmetric ion–atom radiative processes in the solar photosphere

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Abstract. The aim of this research is to show that the radiative processes in strongly non-symmetric ion–atom collisions significantly influence on the opacity of the solar photosphere in UV region. Within this work only the He⁺H⁺ and H⁺A⁺ ion-atom systems, where A is the atom of one of the metal (Mg, Si and Al), are taken in to account. It is caused by the fact that the needed characteristics of the corresponding molecular ions, i.e. molecular potential curves and dipole matrix elements, have been determined by now. Here the non-symmetric radiative processes are considered under the conditions characterizing the non-LTE standard model of the solar atmosphere (Vernazza J, Avrett E and Loser R 1981 ApJS 45 635), which gives the possibility to perform all needed calculations and determined the corresponding spectral absorption coefficients. It is shown that the examined processes generate rather wide quasi-molecular absorption bands in the UV and VUV regions, whose intensity is comparable and sometimes even larger than the intensity of known one’s caused by the H⁺H⁺ radiative collision processes, which are included now in the solar atmosphere models. Consequently, the presented results suggest that the non-symmetric ion-atom absorption processes have to be also included in standard models of the solar atmosphere.

1. Introduction

The significant influence of some ion-atom radiative collision processes on the optical characteristics of the stellar atmospheres was already established. Here we keep in mind such symmetric radiative processes as photo absorption/emission and radiative charge exchange, which can be described by

\[ \varepsilon_\lambda + A_2^+ \leftrightarrow A + A^+ \]  \hspace{1cm} (1)

\[ \varepsilon_\lambda + A^+ + A \leftrightarrow A + A^+ \]  \hspace{1cm} (2)

where A = H(1s) or He(1s²), A⁺ and A₂⁺ are the corresponding positive, single charged atomic and molecular ions in the ground electronic states, and ε_λ - the energy of the photon. It was shown that these processes can influence to the opacity of atmospheres of Sun (see e.g. [2] and [3]). However, the mentioned papers have leaved opened the questions of the significance of the non-symmetric radiative processes.
The main aim of this work is to draw attention to the possible significance of the non-symmetric radiative processes as factors which influence to the opacity of stellar atmosphere in UV and VUV region. Here we will consider the processes of absorption charge exchange and photo-dissociation of the type

$$\varepsilon_\lambda + AB^+ \leftrightarrow A^+ + B$$  \hspace{1cm} (3)

$$\varepsilon_\lambda + A + B^+ \leftrightarrow A^+ + B$$  \hspace{1cm} (4)

$$\varepsilon_\lambda + A + B^+ \leftrightarrow (AB^+)^*$$  \hspace{1cm} (5)

where B is the ground state atom with the ionization potential $I_B$ which is less than the ionization potential $I_A$ of the atom A, $AB^+$ - the corresponding molecular ion in one of the electronic states which are asymptotically correlated with the state of the system $A + B^+$.

Let us note that the processes (3) and (4) represent the analogues of the processes (1) and (2), while the process (5) has not it’s symmetric analog. In this work the non-symmetric radiative processes are considered under the conditions characterizing the models of the solar atmosphere presented in [1].

Namely, all data needed for the calculations of the spectral absorption coefficients are provided in tabular form only for the chosen models. In accordance with this model is possible that $A = \text{He}(1s^2)$ and $B = \text{H}(1s)$, and $A = \text{H}(1s)$ and $B = \text{Mg}, \text{Si}$ and $\text{Al}$. Let us note that for the ions $\text{HeH}^-$ and $(\text{HeH}^+)^*$ the corresponding potential curves and the dipole matrix elements (as the functions of the internuclear distances) are taken from Green et al. [4] and [5], while for all other considered molecular ions the mentioned quantities are calculated within this work.

The corresponding spectral absorption coefficients, as the function of $\lambda$, the local temperature $T$ and the relevant particle densities are determined in the region $40\text{nm} \leq \lambda \leq 230\text{nm}$.

2. Results and discussion

The non-symmetric processes (3) – (5) are schematically shown in figure 1, where: bf-, ff-, and fb denote the bound-free, free-free and free-bound radiative transitions; $\Delta I = I_A - I_B$; $E = E_{\text{imp}}$ and $E'_{\text{imp}}$ are the impact energies of the corresponding ion-atom systems; $U_{\text{in}}(R)$ and $U_{\text{fin}}(R)$ - are the adiabatic potential curves of the initial and final molecular electronic states; $v$, $v'$, $J$, and $J'$ - the quantum numbers of the corresponding bound (ro-vibration) and free states.

The contribution of the considered non-symmetric ion-atom absorption processes (3) - (5) to the opacity of the solar atmosphere is described here by the spectral absorption coefficient $\kappa_{\text{ia;nsim}}(\lambda; T)$. The behavior of $\kappa_{\text{ia;nsim}}(\lambda; T)$ for several values of $\lambda$ is illustrated by figure 2, where $h$ is the distance of considered layer from the referent one ($h=0$) in accordance with Vernazza et al. (1981) [1].

The behavior of the quantity $G = \kappa_{\text{ia;nsim}}(\lambda; T)/ \kappa_{\text{ia;tot}}(\lambda; T)$, where $\kappa_{\text{ia;tot}}(\lambda; T)$ characterize the total contribution of all ion-atom absorption processes, i.e. (1) - (5), is shown in figure 3. Then, in figure 4 is presented the behavior of the quantities $F_{\text{sim}} = \kappa_{\text{ia;sim}}(\lambda; T)/ \kappa_{\text{oa}}(\lambda; T)$ and $F_{\text{tot}} = \kappa_{\text{ia;tot}}(\lambda; T)/ \kappa_{\text{oa}}(\lambda; T)$ - the contribution of the concurrent electron-atom processes (H$^-$ continuum), which were treated until recently as the absolutely dominant.

Even the results presented in these figures shows that the neglecting of the contribution of the non-symmetric processes (3) - (5) to the opacity of the solar atmosphere, in respect to the contribution of symmetric processes (1) and (2) would caused significant errors.

From the presented material it follows that the considered non-symmetric ion-atom absorption processes can not be treated only as one of the channel among many equal channels of the influence on the opacity of the stellar atmospheres and should be included together with the processes studied in our previous papers [6-10].
Figure 1. Schematic presentation of the non-symmetric processes (3-5) caused by the bound-free, free-free and free-bound radiative transitions.

Figure 2. Quiet Sun. Spectral absorption coefficient $\kappa_{\text{ia};\text{nsim}}(\lambda; T)$ for the spectral region $115\text{nm} < \lambda < 195\text{nm}$.

From here it follows that the non-symmetric absorption processes (3)-(5) should be ab initio included in the same models.
Figure 3. The behaviour of the quantity $G = \kappa_{\text{icsim}}(\lambda; T) / \kappa_{\text{itot}}(\lambda; T)$.

Figure 4. The behaviour of the quantities $F_{\text{sim}} = \kappa_{\text{icsim}}(\lambda; T) / \kappa_{\text{esim}}(\lambda; T)$ and $F_{\text{tot}} = \kappa_{\text{itot}}(\lambda; T) / \kappa_{\text{esim}}(\lambda; T)$.

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