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ION-ATOM COLLISIONS AT INTERMEDIATE IMPACT VELOCITIES AS A NEW SOURCE OF UV AND VUV RADIATION

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Abstract. The processes of the radiative charge exchange in $H^+ + H(1s)$ collisions at the intermediate ion-atom impact velocities are treated as a source of continuous EM emission in the far UV range. The spectral intensity of this emission is determined, within the semiclassical method developed in previous works, for the ion-atom impact energies (in the center of mass reference frame) from 0.5 keV to 12.5 keV. The results obtained show that the spectral intensity of the examined EM emission increases for several orders of magnitude when passing from the visible to the VUV range of wavelength, and that the position of the maximum of this spectral intensity drifts with increase of collision energy from $\lambda \simeq 51$ nm to $\lambda \simeq 18$ nm. These results imply that considered radiation processes may be of interest from astrophysical aspect as a new sources of continuous UV and VUV emission.

1. INTRODUCTION

There are some astrophysical object where the relative movement of their plasma greatly exceeds the thermal velocities. The most significant example are the giant streams of the hydrogen plasma (jets), ejected from the central parts of active galaxies. The typical velocities of such jets can be 1000-2500 km/s, as in the case of Akn 120 galaxy (Popović et al., 2001). Another characteristic example are streams of weakly ionized hydrogen plasma (outflows), produced during the creation of young stars (Eisloffel et al., 2000). The velocity of these streams can be greater than 200 km/s. Also, some stars can release the outer layers of their atmospheres. Typical example is the yellow hyper giant ρ-Cassiopeiae, with velocity of weakly ionized layers around 100 km/s (Lobel et al., 2003). Another very interesting case is the formation of two nearly spherically symmetrical layers of hydrogen plasma, an outer (slow wind) and inner (fast wind), moving from the central star with velocities of 20 km/s and 2000 km/s, respectively (Icke, 2003; Kwok, 1982). A great difference in velocities results in strong interaction of these layers, which manifests in non-thermal atom-ion collisions with typical impact velocities at 100 - 1000 km/s.

With regard to all these examples, our primary objective is to show the influence of ion-atom collisions at impact velocities 100-2000 km/s in corresponding astrophysical plasmas. These processes are sources of the UV and VUV electromagnetic emission and are of interest in various diagnostics.

We will consider the following ion-atom collision processes:

$$H^+ + H \rightarrow \varepsilon_\lambda + \left\{ \begin{array}{l} H + H^+ \\ H^+ + H \end{array} \right. \tag{1}$$

in the middle range of impact velocities. Here $H = H(1s)$ denotes a hydrogen atom in its ground state, and ε_λ is the energy of the photon with the wavelength λ. The theory of processes (1) has been developed in two previous papers (Drukarev and Mihajlov, 1974; Ermolaev and Mihajlov, 1991). In the first, a dynamical semiclassical theory of the process (2) was evolved, and in the second, a method (based on this theory) was worked out for calculating spectral characteristics of a group of processes of that type in the range of intermediate collision energies. In Ermolaev and Mihajlov (1991) this method was tested just in the example of the process (1) at impact energies of 10 keV, in the infra-red and visible region. However, the results of later estimations (Mihajlov and Ermolaev, 1998) showed that the intensity of the examined EM emission at these impact energies should increase for several orders of magnitude at transition from the visible into the VUV region. In view of the fact that a proof of such results would imply that the process (1) in the case of the intermediate $H^+ + H$ impact energies may also be interesting in astrophysical aspect, we have performed corresponding calculations of spectral intensity of the EM emission generated in this process. Here we present the results of the calculations of this spectral intensity for wavelengths from visible up to the soft X-ray region, which refer to the $H^+ + H$ impact energies in the center of mass reference frame from 0.5 keV to 12.5 keV.

2. RESULTS AND DISCUSSION

The results of our calculation are presented in Figs. 1, 2 and 3.

One may conclude on the base of the presented results that the radiative process (1) for intermediate impact energies could be of interest from astrophysical point of view, as a new source of EM emission in the UV region and up to the X-rays region, with a conspicuous maximum in the VUV region. First of all, we would like to emphasize the necessity of taking into account the process (1), in situation of two weakly ionized hydrogen plasma layers penetrating one into each other and moving with respect to the other with macroscopic velocity $\approx 10^6 m/s$, since this process can very strongly affect the shape of the considered continuous emission spectra in the UV, and especially in the VUV region. It is clear that all presented here could be applied to the interaction of weakly ionized hydrogen plasma layers with beams of intermediate energy hydrogen ions.

Presented results could be directly used when the relative velocity of the radiation source with respect to the observer, v_r, is much smaller than the speed of light. Namely, our estimations show that in the range $0 \leq v_r \leq 0.01c$ the spectral intensity changes for less than 1% due to Doppler effect. If the source velocity increases up to $0.1c$, the values of $S(\lambda, v)$ might change 10% - 15%. This is due to the fact that the spectrum of EM emission generated in the processes [1] at intermediate impact energies is broad and does not contain sharp maxima and minima. On the other hand, if the velocity of the source increases up to $0.1c$, the values of spectral intensity

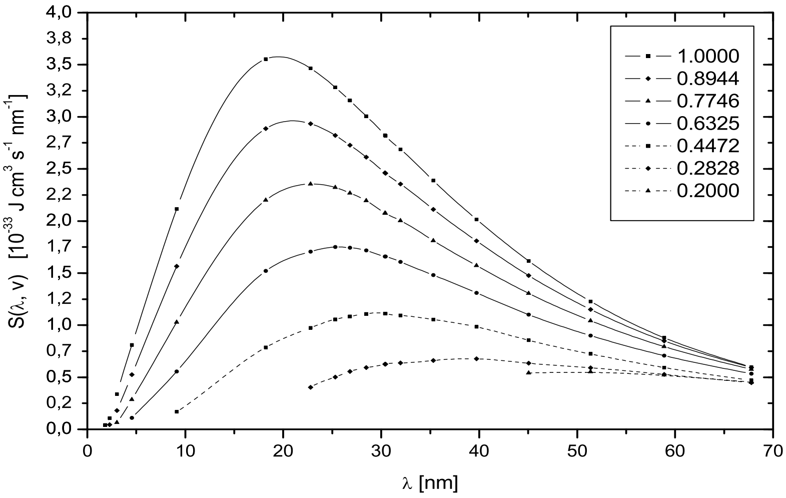

Figure 1: Spectral intensity $S(\lambda, v)$ as a function of wavelength λ, in the region $\lambda \leq 67.79$ nm, for impact velocities v in the range $0.2v_0 \leq v \leq 1.0v_0$.

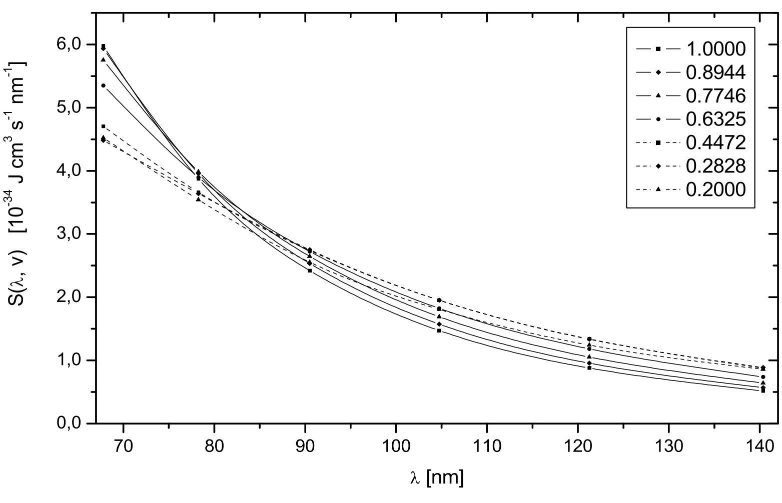

Figure 2: Same as on the Fig. 1, but in the wavelength range 67.79nm $\leq \lambda \leq$ 140.363 nm.

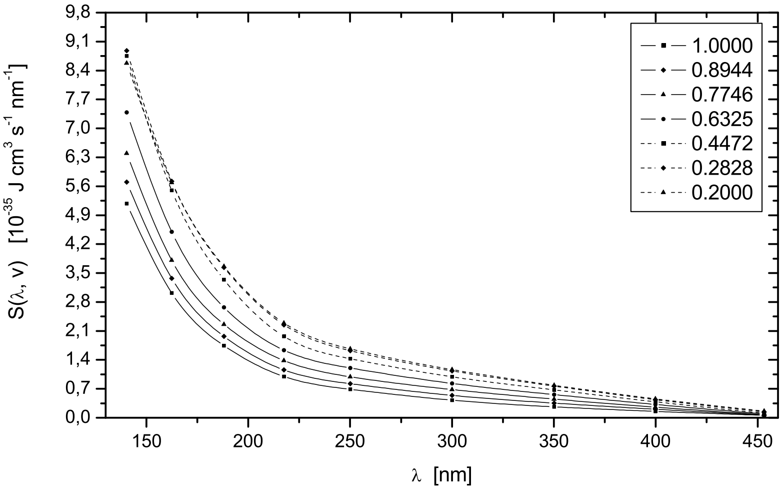

Figure 3: Same as on the Fig. 1, but in the wavelength range $\lambda \geq 140.363$ nm.

would change for 10% to 15% from the ones presented here, which would in general require additional elaboration. However, one should keep in mind that for practical purposes such an accuracy of determination of the spectral intensity of EM emission is often quite acceptable.

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