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ION-ATOM RADIATIVE COLLISIONS AND THE OPACITY OF THE SOLAR ATMOSPHERE

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1. INTRODUCTION

The continuum opacity of the solar atmosphere in the visible range is dominated by radiation exchanges in formation and dissociation of the H^- ion: $H + e \leftrightarrow h\nu + H^-$ (see Mihalas 1978). However other processes involving atoms and positive ions may also play a role in the opacity. The purpose of the present paper is to evaluate the contribution of these processes to the opacity. We will limit ourselves to the optical part of the electromagnetic spectrum (350 to 1250 nm) where the theory of the various processes involved can be considered as correct.

2. ATOMIC AND MOLECULAR RADIATIVE PROCESSES IN THE SOLAR ATMOSPHERE

The following processes can play a role in determining the opacity of the solar atmosphere.

i) positive ion - atom interactions:

$$A^+ + A \leftrightarrow \varepsilon_\lambda + \begin{cases} A + A^+ & \text{(radiative charge exchange),} \\ A_2^+ & \text{(ion-atom photoassociation),} \end{cases} \quad (1)$$

where is $\varepsilon_\lambda = h\nu = 2\pi\hbar c/\lambda$ is the energy of the interacting photon;

ii) free-free and free-bound process involving a positive ion:

$$A^+ + e \leftrightarrow \varepsilon_\lambda + \begin{cases} A^+ + e, \\ A^*, \end{cases} \quad (2)$$

where A^* is an atom in an excited state;

iii) free-free processes in the field of an atom:

$$A + e <-> \varepsilon_\lambda + A + e; \quad (3)$$

iv) formation and dissociation of H^-:

$$A + e <-> \varepsilon_\lambda + H^-. \quad (4)$$

In order to compare different processes, we will define the ratios (F) of emissivities (ε):

$$F_{ei}(\lambda) = \varepsilon_{ia}(\lambda) / \varepsilon_{ei}(\lambda), \quad (5a)$$

$$F^{ff}_{ea}(\lambda) = \varepsilon_{ia}(\lambda) / \varepsilon^{ff}_{ea}(\lambda), \quad (5b)$$

$$F^{fb}_{ea}(\lambda) = \varepsilon_{ia}(\lambda) / \varepsilon^{fb}_{ea}(\lambda), \quad (5c)$$

characterizing relative contribution of the process (1) in comparison with processes (2), (3) and (4) respectively. The meaning of indexes is: ei - electron-ion; ia - ion-atom; ea - electron-atom; ff - free-free; fb - free-bound. In the case of local thermal equilibrium, these ratios are also the ratios of the corresponding absorption coefficients.

All details of the calculations will be published in Mihajlov et al 1993. Here we present and discuss only the results for the solar atmosphere.

3. RESULT FOR THE SOLAR ATMOSPHERE AND DISCUSSION

Our calculation have been performed by using LTE solar photospheric model of Maltby et al. (1986) (their Table 11, photosheric reference model) for altitudes (h) lower than 600 km and chromospheric model of Vernazza et al.(1981) (their model C) for higher altitudes.

The comparison of (1) and (2) processes contribution is presented in Fig. 1 where the behavior of $F_{ia}(\lambda)$ as a function of height (h) is demonstrated (with f is denoted the correction factor close to unity defined in Mihajlov et al 1993). We can see two maxima, one in the photosphere and the other one in the chromosphere. This means that in these areas ion-atom radiation processes (1), not taken into account up to now, have the dominant role in the comparison with processes (2) for continuous emission (absorption) EM spectrum formation.

The comparison of (1) and (3) processes contribution is presented in Fig. 2 where the behavior of $F^{ff}_{ea}(\lambda)$ is demonstrated. One can see the photospheric and the chromospheric maximum of $F^{ff}_{ea}(\lambda)$ located in the same height range as for $F_{ei}(\lambda)$ in Fig. 1. These maxima however are of smaller intensity.

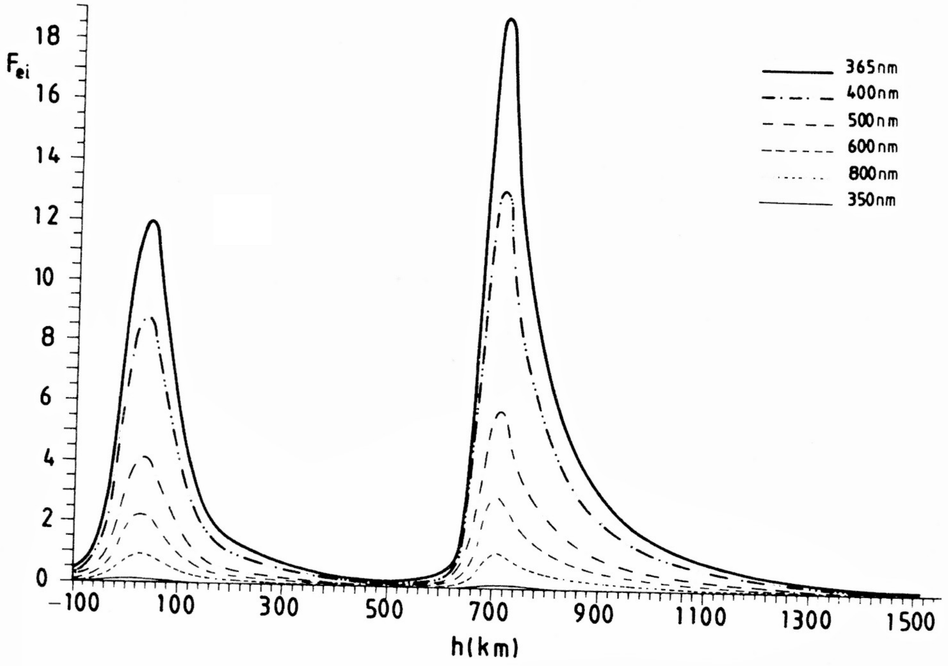

Fig. 1 The parameter $F_{ei}(\lambda)$, for $f_{ei}=1$, in the 350 nm$\leq\lambda\leq$800 nm range (350 nm$<\lambda_2<$365 nm), as a function of *h*

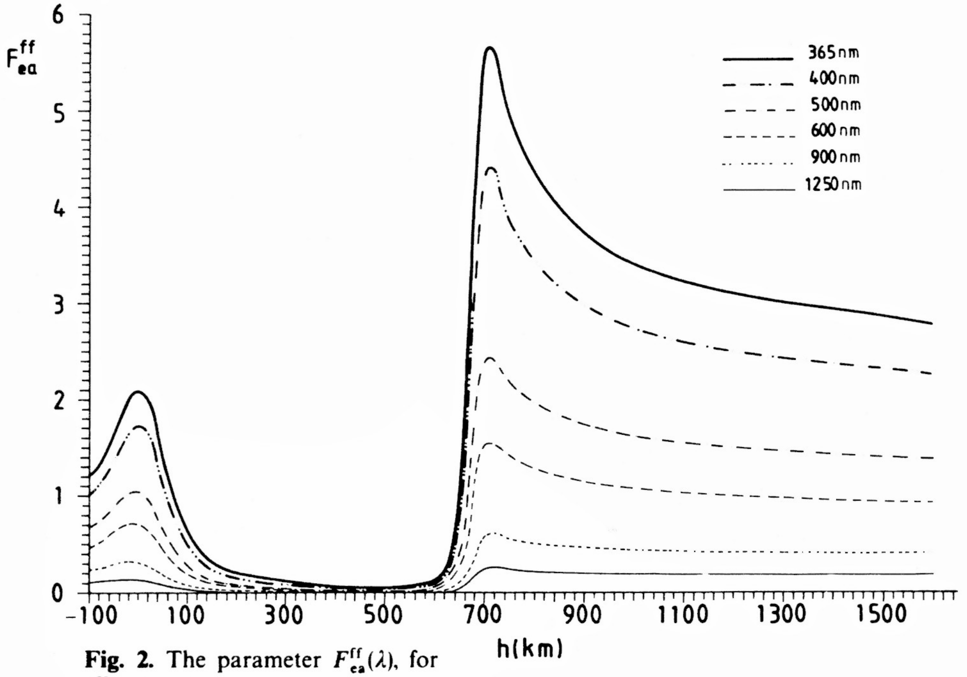

Fig. 2. The parameter $F_{ea}^{ff}(\lambda)$, for $f_{ea}^{ff}=1$, in the 350 nm$\leq\lambda\leq$ 1250 nm range, as a function of *h*

In considered photosperic and chromospheric regions, electron-atom processes are always dominant for wavelengts larger than 1250 nm, including the infrared part of the spectrum at 1650 nm, where the minimum in H minus absorption occurs. Our calculation however, show that for sophysticated investigations ion-atom processes must be taken into account around 1650 nm since in the layers considered, the contribution of these processes is 5-15 percents of electron-atom ones.

Our calculations show that values of $F^{fb}_{ea}(\lambda)$ parameter change from $\approx$ 0.15 up to $\approx$ 0.05 in the -100 km $\le$ h $\le$ 50km, decrease slowly up to around 700 km and increases steply up to $\approx$ 0.1. After 700 km increases very slowly for all λ considered.

Our results show that the processes (1), not taken into account up to now for photosphera and chromosphera research from the spectroscopical point of view, are not negligibile and in particular layers become in fact even comparable with processes (4), the most important for continuous emission (absorption) spectrum formation for height range considered.

Present calculations for layer between h = 0 km and h = 605 km show that with the inclusion of processes (1), the continuum emergent intensity from this photospheric layer decreases from 0.28 percents at 500nm up to 0.14 percents at 800nm. We can conclude that in spite of the fact that the contribution of processes (1) to the total absorption spectrum is around 10% in particular atmospheric layers, the total contribution for the photosphera as the whole is less than 1 percent. This is the consequence of the fact that layers where the investigated processes (1) are of interest, represent only a small part of the photosphera, and in large parts of photosphera the proton density is so small that the contribution of processes (1) to the total absorption coefficient may be neglected.

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