CALCULATION OF RADIATIVE ENERGY TRANSFER IN SPECTRAL LINES

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We have proposed [1] a method for calculating the radiative heat transfer via spectral lines with allowance for reabsorption on the assumption of local thermal equilibrium. Here we give results for some examples.

1. The method [1] of averaging the absorption coefficient has been tested for various temperature distributions (1-3 in Fig. 1), 2 being more rounded than the curve 1 of [1], while 3 has no discontinuity. Figures 2-5 give the results, the solid lines being exact solutions, while the dashed lines represent solutions from averaging [1] the absorption coefficients via

$$\langle k_j \rangle = \left[\int_{\Delta\nu_j} k_\nu \, d\nu\right]^{1/2} \left[\int_{\Delta\nu_j} \frac{d\nu}{k_\nu}\right]^{-1/2}. \qquad (1.1)$$

The numbers on the curves give the number of intervals into which the spectral range $\Delta\nu$ was divided. For distributions 1 and 2, division of $\Delta\nu$ into three parts (circles in Figs. 2 and 3) gives very nearly the exact result, while for distribution 3 it is sufficient to divide the interval into two parts (circles in Figs. 4 and 5).

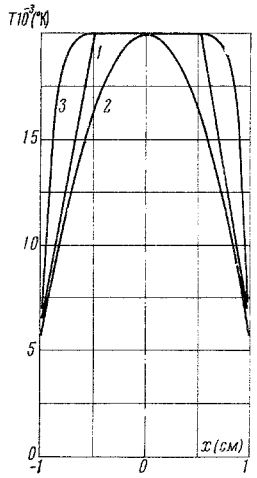

Fig. 1

2. We have discussed [1] a method of considering a system of spectral lines with a common lower state (or group of closely spaced states); such a system may be considered via a single set of mean absorption coefficients, the entire range of absorption coefficients for the group of

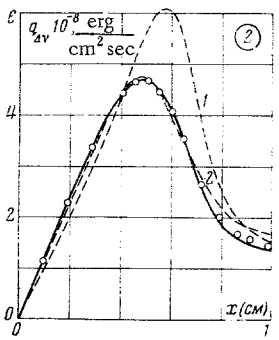

Fig. 2

lines being divided into parts, within each of which the absorption coefficient varies by approximately the same factor (Fig. 6). The number of parts is chosen on the basis of the permissible error [1]. The end values of the range in the absorption coefficient are determined from the detailed parameters of the problem. The division should be performed for a temperature significant for the formation of the radiative-transfer characteristics.

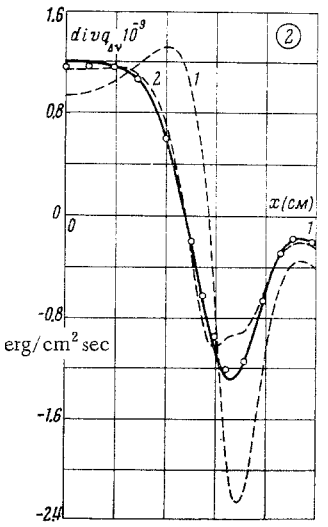

Fig. 3

The above division defines certain frequency ranges, which are retained for other temperatures. The absorption coefficient is averaged over each interval, and the resulting values for the strongest line in the group are used to calculate the heat transfer for all lines in the group. If all lines in a given range of absorption coefficient have the shape

$$k_\nu = \frac{A(T)}{(\nu - \nu_0)^m}, \qquad (2.1)$$

then it can be shown that the $\langle k \rangle$ of (1.1) will be dependent mainly on the boundary values of k_ν, but very little on m. The rule becomes approximate if the relationship is more general than that of (2.1).

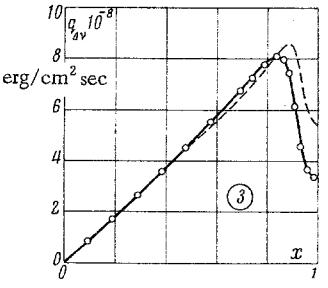

Fig. 4

The entire group of lines is then described by $\langle k_1 \rangle$, $\langle k_2 \rangle$, etc; the equilibrium radiation density corresponding to a given $\langle k_j \rangle$ is, for a symmetrical line, of the form

$$2\left(u_{\nu_1}{}^0 \Delta\nu_j^{(1)} + u_{\nu_2}{}^0 \Delta\nu_j^{(2)} + \ldots\right). \qquad (2.2)$$

Here $u^0_{\nu_j}$ is the equilibrium spectral density of the radiant energy at the line center, and $\Delta\nu_j^{(i)}$ is the range of frequencies for line i corresponding to $\langle k_j \rangle$.

This has been tested by calculating the radiation transport in a system of two resonance lines of Ar: the line previously examined (ν_0 = $= 2.86 \cdot 10^{12}$ sec^{-1}, oscillator strength 0.2) was taken with the line ν_0 =

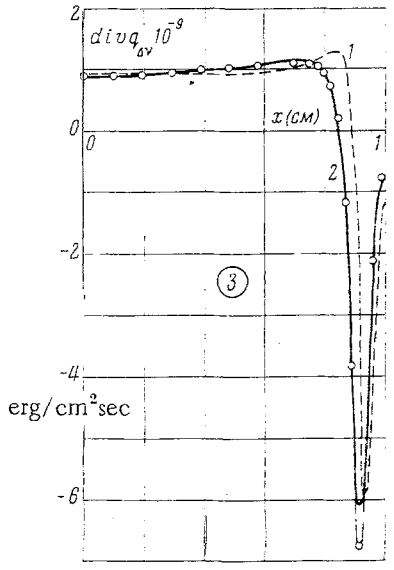

Fig. 5

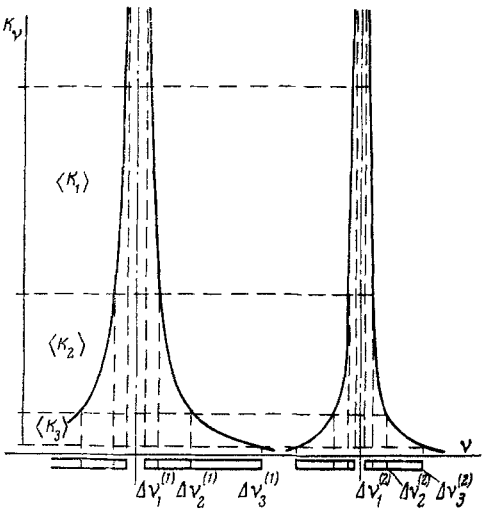

Fig. 6

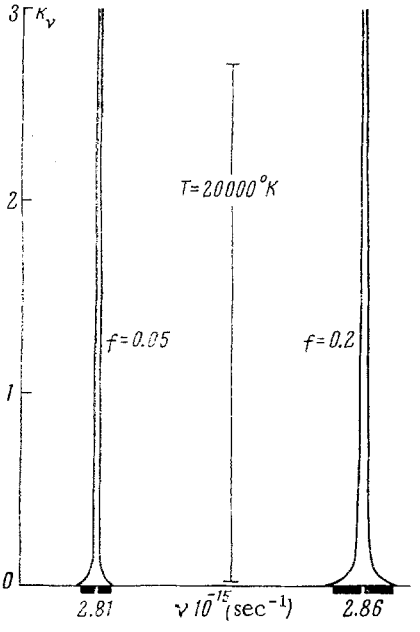

Fig. 7

= $2.81 \cdot 10^{12}$ sec^{-1}, oscillator strength 0.05. Figure 7 shows both lines for 20 000° K; the black rectangles on the abscissa indicate the frequency regions used in the calculations, while the arrow shows the range of absorption coefficients taken into account. The K_ν of Figs. 7 and 8 have the dimensions cm^{-1}.

Figure 8 shows the K_ν for these lines at the corresponding frequencies as functions of T; curve 1 is for $\nu - \nu_{01} = 10^{12}$ sec^{-1}, while curve 2 is for $\nu - \nu_{02} = 0.5 \cdot 10^{12}$ sec^{-1}. The initially identical absorption coefficients diverge for T ≤ 12 000° K, and they differ by a factor of four

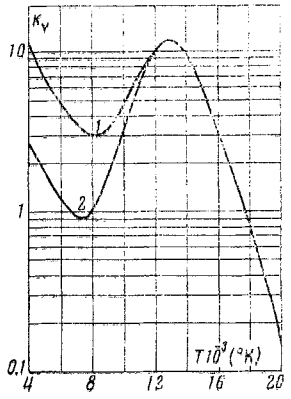

Fig. 8

at 6000° K. Figures 9 and 10 show $q_{\Delta\nu}$ and div $q_{\Delta\nu}$ derived from distribution 2 of Fig. 1 for these lines individually (curves 1 and 2), for the sum (curve 1 + 2), and the energy transport in the two lines on using the absorption coefficient for the line with $f = 0.2$ (dashed line). It is clear that a difference occurs only over a narrow range and in any case is slight. Distribution 3 gives even less difference.

3. The P_1 diffusion approximation has [1] been prepared with the exact solution, with indication of the possible error. Calculations for other temperature distributions gave approximately the same results. The more exact method of description of the transport was considered via the P_3 approximation in the spherical-harmonics method [2-4].

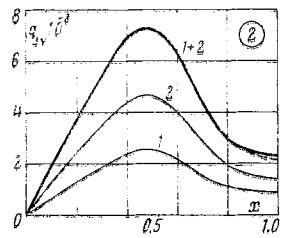

Fig. 9

This approximation in the planar case gives an integral expression analogous to the solution in approximation P_1. Computations show that the error of P_3 is about half of that of P_1. Figure 11 reproduces Fig. 3 of [1], the dot-and-dash line representing the P_3 solution. (Here the plasma composition at high temperatures was used in more accurate form than in [1]; the calculations for Fig. 11 were performed with the former composition.) The dimensions in Figs. 9-11 are as in Figs. 2-5; the numbers within circles are the distribution numbers of Fig. 1.

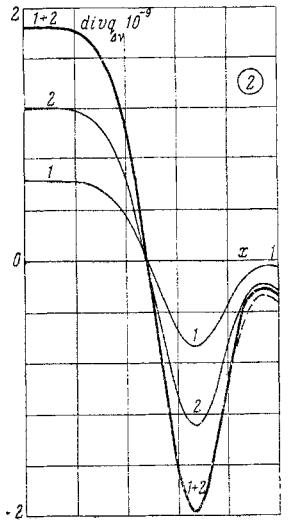

Fig. 10

4. This method, being numerical, is applicable to spectral lines of any shape and to an arbitrary temperature distribution in the gas.

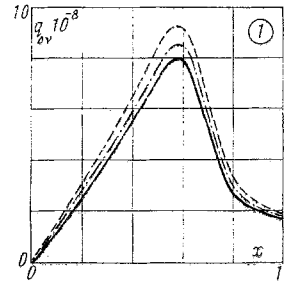

Fig. 11

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