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RESONANCE-BROADENING ABSORPTION IN THE WINGS OF LYMAN ALPHA

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ABSTRACT

It is pointed out that the conventional formula describing absorption in the wings of Lyman alpha seriously overestimates the magnitude of the absorption at long wavelengths, and it seems improbable that the resonance-broadened wings of Lyman alpha are a significant source of opacity at wavelengths in excess of 2000 Å.

It has been suggested recently (Cuny 1969; Strom and Strom 1969; Gingerich 1969) that the resonance-broadened wings of Lyman alpha are an important source of opacity in the solar spectrum and in the atmospheres of F- and G-type subdwarfs, and calculations of solar fluxes for the new Harvard-Smithsonian Reference Solar Atmosphere (Gingerich 1969) have shown that the Lyman-alpha opacity source significantly depresses the continuum in the region of the Balmer discontinuity at 3650 Å.

These studies adopted the conventional formula for the resonance-broadening contribution to the absorption coefficient at wavelength λ (Å) (cf. Jefferies 1968):

$$a = 1.9 \times 10^{-48} n(\mathrm{H})\ (1/\lambda - 1/1216)^{-2}, \qquad (1)$$

where n(H) is the number density of perturbing hydrogen atoms. The formula follows from the binary quasi-static description of collision broadening with the assumption that the interaction between a ground-state hydrogen atom H(1s) and an excited-state hydrogen atom H(2p) decreases as the inverse cube of the nuclear separation R (cf. Breene 1961). In the quasi-static or quasi-molecular description, the broadening arises from the modifications of the energy separation of the initial and final states caused by the approach of a perturbing atom, and the absorption in the wings of the Lyman-alpha line can be attributed to transitions from the initial states of the quasi-molecule formed by the approach of H(1s) and H(1s) to the final states formed by the approach of H(1s) and H(2p). Except that the transition probability at infinite nuclear separation is finite, the process is analogous to the quasi-molecular absorption,

$$\mathrm{H}_2(1s\sigma 2p\sigma\ {}^3\Sigma_u^+) + h\nu \rightarrow \mathrm{H}_2(1s\sigma 2s\sigma\ {}^3\Sigma_g^+),$$

discussed by Erkovich (1960), Solomon (1964), Soshnikov (1964), and Doyle (1968).

The quasi-static description is valid in the wings of the line, where the associated radiative decay time is short compared to the collision time, but the R^{-3} dependence of the interaction is correct only at large internuclear distances at which the wavelength separation of the initial and final quasi-molecular states is necessarily near that of the line center. Figure 1 illustrates the interaction potentials of the initial $X\ {}^1\Sigma_g^+$ state and the final $B\ {}^1\Sigma_u^+$ state. Departures from the limiting R^{-3} dependence of the $B\ {}^1\Sigma_u^+$ state are severe at separations R smaller than $12a_0$ (Kolos 1967), and the derivation of the conventional formula (1) fails at wavelengths longer than 1228 Å.

We have carried out a semiclassical calculation of the quasi-molecular $X\ {}^1\Sigma_g^+$–$B\ {}^1\Sigma_u^+$ absorption at 5000° K, using the accurate interaction potentials of Kolos and Wol-

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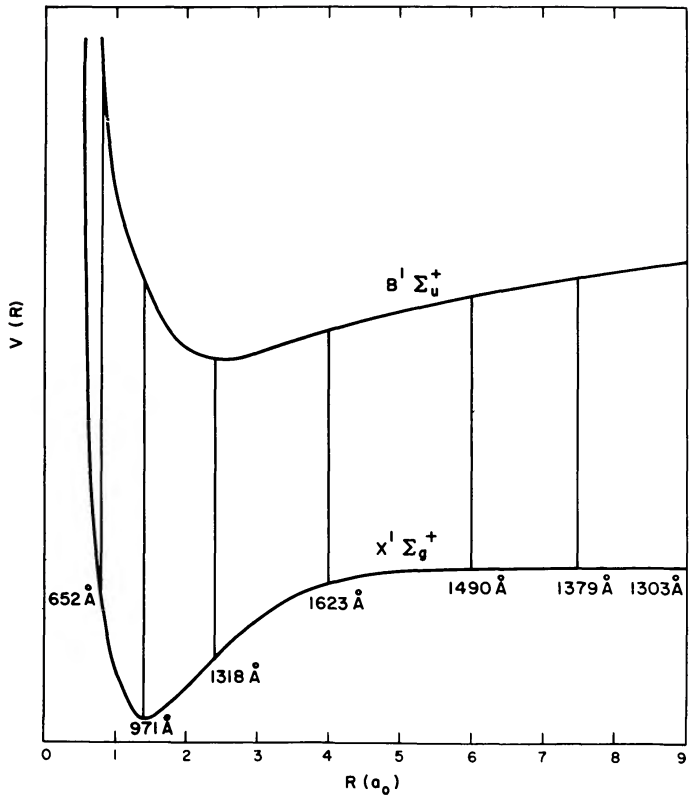

Fig. 1.—Interaction potentials in the $X\,^1\Sigma_g^+$ and $B\,^1\Sigma_u^+$ states of H_2, showing their energy separations in wavelengths at different internuclear distances.

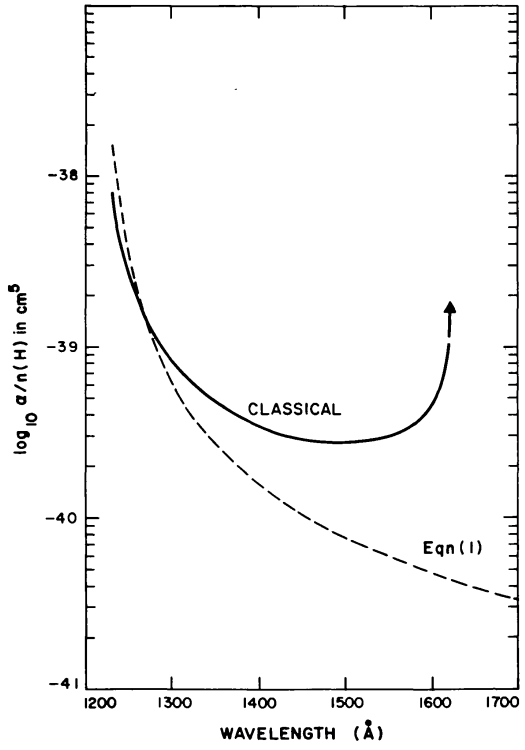

FIG. 2.—Absorption coefficient α for unit density using the classical theory and using the standard formula. For density n(H) cm^{-3} the absorption coefficient is $\alpha[n(\mathrm{H})]^2$ cm^{-1}.

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niewicz (1965, 1966) and the dipole-moment function of Browne (1969). The resulting absorption coefficient is shown in Figure 2. Between 1280 and 1623 Å the absorption coefficient is larger than that predicted by equation (1), but for wavelengths longer than 1623 Å it vanishes. The critical wavelength 1623 Å is the wavelength separation at the closest approach, $R = 4.1a_0$, of the initial and final potential-energy curves, shown in Figure 1. In practice, the absorption coefficient does not vanish at longer wavelengths, because it is possible for the colliding atoms to change their relative momentum during the absorption process. It is clear, however, that the absorption coefficient will decrease exponentially with increasing wavelength above 1623 Å, and we expect the absorption to be negligible at wavelengths exceeding 2000 Å. Full quantal calculations are in progress.

The $X\ ^1\Sigma_g^+$–$C\ ^1\Pi_u$ transition and the $b\ ^3\Sigma_u^+$–$h\ ^3\Sigma_g^+$ and $b\ ^3\Sigma_u^+$–$i\ ^3\Pi_g$ transitions of the quasi-molecule (cf. Herzberg 1950) also contribute to the resonance broadening of the Lyman-alpha wings. The classical limit of the $X\ ^1\Sigma_g^+$–$C\ ^1\Pi_u$ transition occurs at 1269 Å, and the $b\ ^3\Sigma_u^+$ is repulsive over a wide range of separations, so that a close approach (which might lead to absorption at long wavelengths) rarely takes place. We conclude that the resonance-broadening absorption in the Lyman-alpha wings at wavelengths in excess of, say, 2000 Å is substantially smaller than that given by the standard expression (1).

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