Asian Journal of Physics Vol 10, NO. 1, (2001) 42-44

Molecular band absorption and interaction of 1.15 μm, laser beam with water vapour lines*

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One of the elementary models of molecular band absorption is the quasi-random model. This model is employed in this work to study the interaction of 1.15 p.m laser beam with the nearby water vapour absorption lines. The wavenumber interval used is 8676-8680 cm^{-1}.© Anita Publications. All rights reserved.

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1 Introduction

One can calculate the frequency-dependent absorptive power of a gas by four types of elementary models : the statistical model, the Elsasser model, the random Elsasser model and the quasi-random model [1]. The statistical model is useful when the spectral lines exhibit a random distribution in a given frequency interval. The Elsasser model describes absorption by a system whose characteristic spectra consists of lines that are nearly uniform in spacing with respect to one another. The random Elsasser model is a combination of the statistical and Elsasser models : it describes absorption by a system of randomly distributed bands, each of which has a uniform, though perhaps different, spacing. The quasi-random model, when treated with the aid of electronic computers, can handle the most general type of band arrangements. It has been conveniently applied to CO_2 and H_2O.

2 Atmospheric transmission of a laser beam

An understanding of the transmission of electromagnetic radiation through the earth's atmosphere is important to many aspects of space science. The passage of a laser beam through the atmosphere presents an important transmission problem, a novel aspect of which is the almost monochromatic nature of a laser beam. High intensity is a special feature of many recent lasers, and many complex non-linear effects occur during their passage through the atmosphere. The propagation of high energy laser beams through the atmosphere is often dominated by interactions with atmospheric aerosols, which can scatter and absorb energy from the beam. For low irradiance beams, aerosol scattering and linear absorption processes are the dominant mechanisms, removing energy from the beam [2]. In this work, we consider a low enegy laser beam (cw) of wavelength 1.15 μm, propagating through a cloud of water vapour. The effect of aerosols is neglected in the calculations. It is to be noted that 1.15 μm is one of the many helium-neon lasers operating in the near-infrared region. In this region, water vapour molecules have five absorption lines : 11522.77 Ǻ, 11523.19 Ǻ, 11523.73 Ǻ, 11524.20 Ǻ and 11524.23 Ǻ. The first belongs to the 210 band, whereas the other four belong to the much stronger 111 band. The attenuation at the laser frequency is due to the sum of the absorptions arising from each line. Earlier, propagation of a strictly monochromatic radiation in the 1-10 μm region was shown [3], using an empirical relation and with the help of experimental data. Atmospheric transmission of a laser beam with wavelength 6943 Ǻ was calculated [4] without the use of any molecular band absorption model. The important ruby laser line at 6943 Ǻ is very close to the oxygen absorption band of the atmosphere. Therefore, the practical use of the beam in atmospheric transmission is somewhat limited.

[*] Paper presented at National Conference on Lasers and Spectroscopy, Feb 25-28, 1999, Meerut College, Meerut, India.

3 Quasi-random model

The quasi-random model has many distinguishing features in addition to its accurate determinations of the wing effects. Each band interval Ω, over which the average transmittance is required, is further divided into smaller intervals. These intervals are chosen small enough so that the lines falling into any one of them may be considered to lie at random, without introducing any serious errors. Thus, the quasi-random model localises each line within an error defined by the small interval δ. If the size of these elementary intervals were decreased indefinitely, the model would locate each line exactly. Hence, these intervals are chosen small enough to ensure an accurate description of the important band characteristics.

The spectral intensity variations can also be simulated by quasi-random model. The n_p lines falling within a given frequency interval δ_p are divided into intensity groups according to the order of magnitude of their strength. All the lines falling within a given order of magnitude are subsequently averaged, and each line in each intensity decade is then associated with the appropriate average value. In the quasi-random model, the top five intensity sectors in each frequency interval are adequate to describe the absorptive properties associated with the lines. Thus the mathematical expression for the transmittance at a frequency v as affected by the n_p lines in the frequency interval δ_p is given by'

$$T(v) = \prod_{i=1}^{5} \{(1/\delta) \int_{\delta_p} \exp[--S_i u b(v, v_i)] dv_i\}^{n_i} \qquad (1)$$

where n_i represents the number of lines within the intensity range i, which itself is characterised by an average intensity S_i, u is absorber thickness, $b(v,v_i)$ is the Lorentz shape factor defined by

$$b(v,v_i) = \frac{\alpha/\pi}{(v,v_i)^2 + \alpha^2} \qquad (2)$$

(α is the half-width, i.e. half the frequency difference between the half-maximum points, and v_i refers to the centre of the line)

4 Calculation of the transmittance

The frequency interval 8676-8680 cm^{-1} is divided into intervals 0.2 cm^{-1} (f 2) wide. Each interval is further divided into smaller intervals 0.04 cm^{-1} (5). We take S_1= 0.1 for the first absorbing line at v, = 8678.4688 cm^{-1} (210 band), and S_2, S_3, S_4 and S_5 equal to 0.3 for v_l = 8678.1525 cm^{-1}, v_3= 8677.7458 cm^{-1}, v_4 = 8677.3919 cm^{-1} and v_2 = 8677.3693 cm^{-1}. All the five lines are inside the frequency interval 8676-8680 cm^{-1}. The half-width (a) of the lines is taken as 0.01 cm^{-1}. Using Simpson's rule of numerical integration, Eq (1) is evaluated with the help of a computer program for two different masses per unit area (u) : 0.5 pr-cm and 50 pr-cm. As can be expected, calculations based on the quasi-random model are quite time-consuming and complex. First, the transmittance values are calculated at the centres of 0.2 cm^{-1} intervals. Transmittances by the wings of lines at the left and right adjacent intervals are also included. The transmittance at the centre of an interval is finally obtained as^s

$$T = T_j \prod_{i \neq j} T_i \qquad (3)$$

Next, transmittance values are obtained for another set of frequency intervals whose centres are shifted by half the interval size (0.1 cm^{-1}). This is done in order to minimise the error associated with the occurence of lines at frequencies near the edges of a given interval. The results for the shifted and unshifted intervals are averaged, and thus we obtain the average transmittance over a 0.2 cm^{-1} interval.

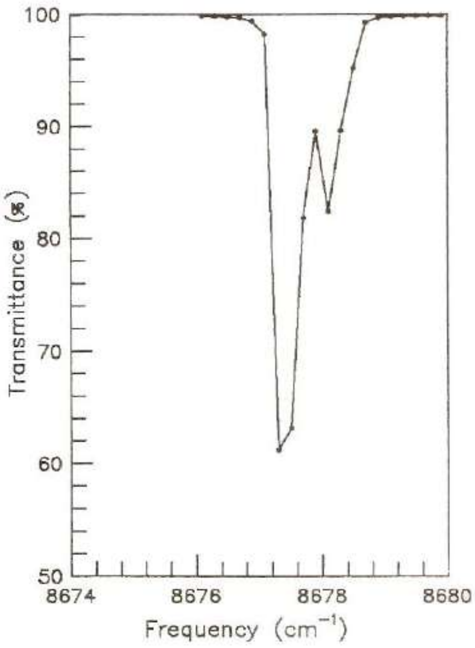

Fig 1. Transmission of 1.15 μm laser beam through 0.5 pr-cm path length of water vapour.

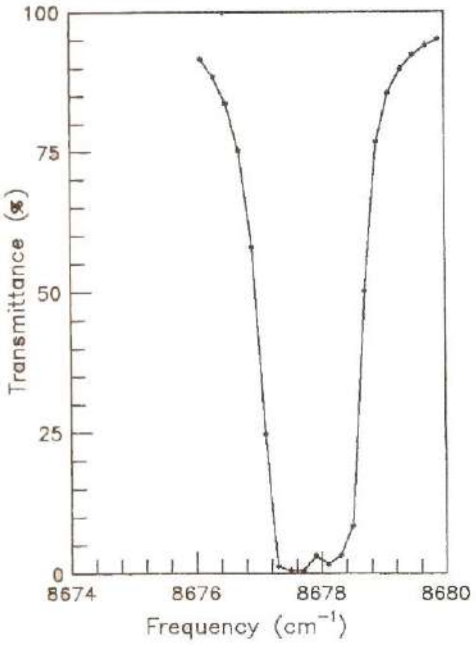

Fig 2. Transmission of 1.15 μm laser beam through 50 pr-cm path length of water vapour.

To illustrate the results of our analysis, we plot the transmittance versus frequency for 0.5 pr-cm and 50 pr-cm path lengths of water vapour, as shown in Figs 1 and 2, respectively. Calculations based on the quasi-random model have been done earlier' for CO_2 and the results fitted well with experimental measurement. Though the present work lacks the experimental verification, it is reasonable to believe that the quasi-random model of molecular band absorption may be used and tested for a particular case of transmission of a low power laser beam through the atmosphere.

Acknowledgment

The calculations are carried out at the Laboratory of the Department of Computer Engineering, Nowgong Polytechnic, Nagaon-782 001, India. One of the authors (AGB) thankfully acknowledges the help at the laboratory of P L Bora, Directorate of Instrumentation, DRDL, Hyderabad-500058, India.

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[Received: 19.7.2000]