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A brief idea on application of the Quasi Random Model to study the propagation of a laser beam through water vapour.

Surajit Bhuyan
Department of Physics, Lakhimpur Girls' College
North Lakhimpur-787031, India
Corresponding author:E-mail ID: surajit_nlp@rediffmail.com

Abstract

Interaction of a Ti: sapphire laser beam of wavelength 9335 Å with the near-infrared absorption lines of water vapour is studied — using the quasi-random model of molecular band absorption. Values of transmittance, averaged over intervals of 0.1 cm^{-1}, are obtained for three different absorber thickness. From these values, intensities of the high-resolution absorption lines of water vapour are simulated in the vicinity of 10712 cm^{-1}

1. Introduction

Water is a very important molecule for the transmission of radiation through the earth's atmosphere. As a matter of fact, it is molecule number 1 in the HITRAN 2004 database [1]. Using a three-wavelength differential absorption lidar technique and water vapour absorption lines, simultaneous measurements of atmospheric temperature and humidity have been done [2] — achieving a 2.3^{0}C absolute accuracy. The accuracy of water line parameters has been an issue in many recent publications and discussions. The absorption spectrum of water vapour in the frequency range 10711.5 - 10712.4 cm^{-1} has been measured, using a frequency-stabilized cavity-ring-down spectrometer with automated scanning capabilities [3]. This spectral region contains nine weak transitions of $H_2{}^{16}O$ and $H_2{}^{18}O$ that correspond to rotational transitions of the $2\nu_1+\nu_3$ combination vibrational band. The frequency 10712.1415 cm^{-1} has been reported by Rothman et al. [4], while those of the other eight by Mérienne et al. [5]. It is worthwhile to mention here that detailed calculations covering this region have also been done [6, 7].

The method used in this work, the quasi-random model of molecular band absorption, is a variant of one of the methods described by Goody and Yung [8]. In their monograph, Goody and Yung have contrasted the use of random models with the line by line method, and concluded that in some circumstances the random models might be sufficient, and require much less computer time. The quasi-random model has been used in the calculation of infrared transmittance of water vapour in the region 1050.0 - 9950.0 cm^{-1} [9], in the study of interaction of the 1.15 μm He-Ne laser beam with the nearby five absorption lines of water vapour at 11522.77, 11523.19, 11523.73, 11524.20 and 11524.23 Å [10], and in the simulation of the intensities of the absorption lines of nitrogen around 575 nm [11]. Recently, applicability of this model in optics of the atmosphere, especially of the upper atmosphere, has been shown [12]-[14].

2. Method of calculation

High-resolution near-infrared absorption spectrum of water vapour [3] is considered in the vicinity of 10712 cm^{-1}. The maximum relative intensity is normalized to unity and other values of intensity are taken relative to this one. The lines along with the assigned intensities are given in Table 1. The entire spectrum in the range 10711.5 - 10712.4 cm^{-1} is divided into frequency intervals Ω = 0.1 cm^{-1} wide. These Ωs are the intervals over which the average transmittances have been computed. Each interval is further divided into smaller intervals δ = 0.02 cm^{-1}. The quasi-random model localizes each line within an error defined by the interval size δ. The transmittance at a frequency ν, as affected by n_p lines within the interval δ_p is computed from the expression [15]

$$\Im(\nu)=\prod_{i=1}^{5}\left\{(1/\delta)\int_{\delta_p}\exp\left[-\frac{S_i u\alpha/\pi}{(\nu-\nu_i)^2+\alpha^2}\right]d\nu_i\right\}^{n_i},$$

where n_i represents the number of lines within the intensity range i, which itself is characterized by an average intensity S_i, α is the half width at half maximum, u is the absorber thickness, and ν_i refers to the centre of the line. It is worthwhile to mention here that as the water vapours are condensable, therefore it is convenient to measure the total length (in centimetres) of the liquid which may be precipitated out of the path (per unit area). The number of precipatable centimeters (pr-cm) of water vapour in a given path of length L centimetres is given by

$$u=\rho(T)\kappa L,$$

where ρ(T) is the saturation vapour density of water at temperature T, and κ is the fractional relative humidity. For three different masses per unit area, u = 0.01, 0.1 and 1.0 pr-cm, and taking the half-width as α=0.015 cm^{-1}, Eq. (1) is evaluated with the help of a computer program based on Simpson's rule of numerical integration. First, the transmittance values are calculated at the centres of 0.1 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 [16]

$$\Im = \Im_j \prod_{i \neq j} \Im_i \qquad (3)$$

Next, transmittance values are obtained for another set of frequency intervals whose centres are shifted by half the interval size (0.05 cm^{-1}) from the original positions of the centres of the intervals. This is done in order to minimize the error associated with the occurrence lines at frequencies near the edges of a given interval. The results for the shifted and un-shifted intervals are averaged, and thus we obtain the average transmittance over a 0.1 cm^{-1} interval.

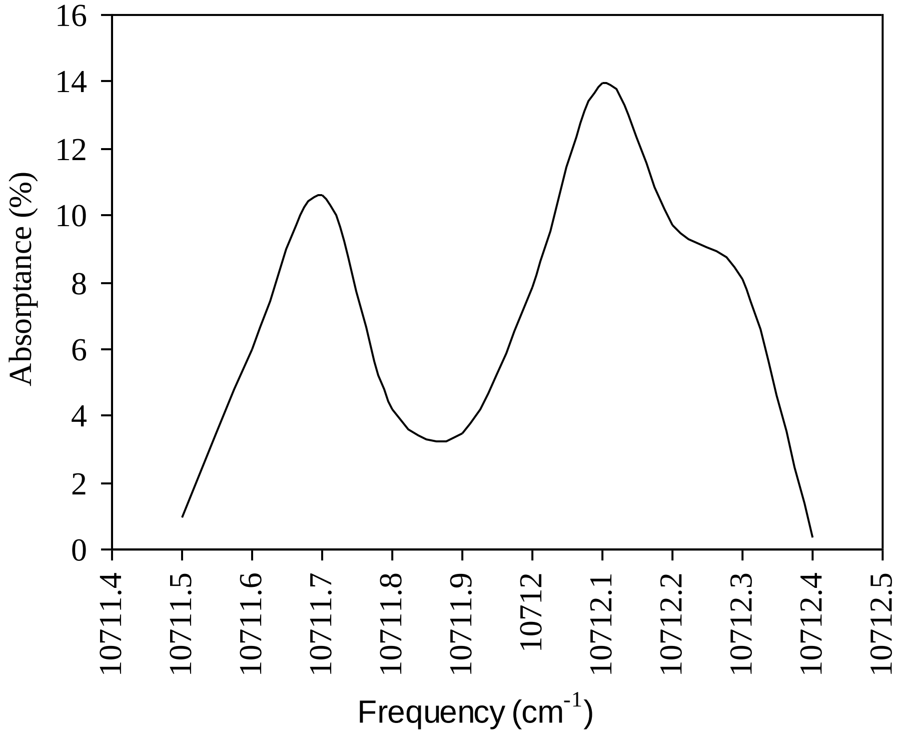

Figure 1. Absorptance of a 9335 Å Ti:sapphire laser beam for a for 0.01 pr-cm path length of water vapour.

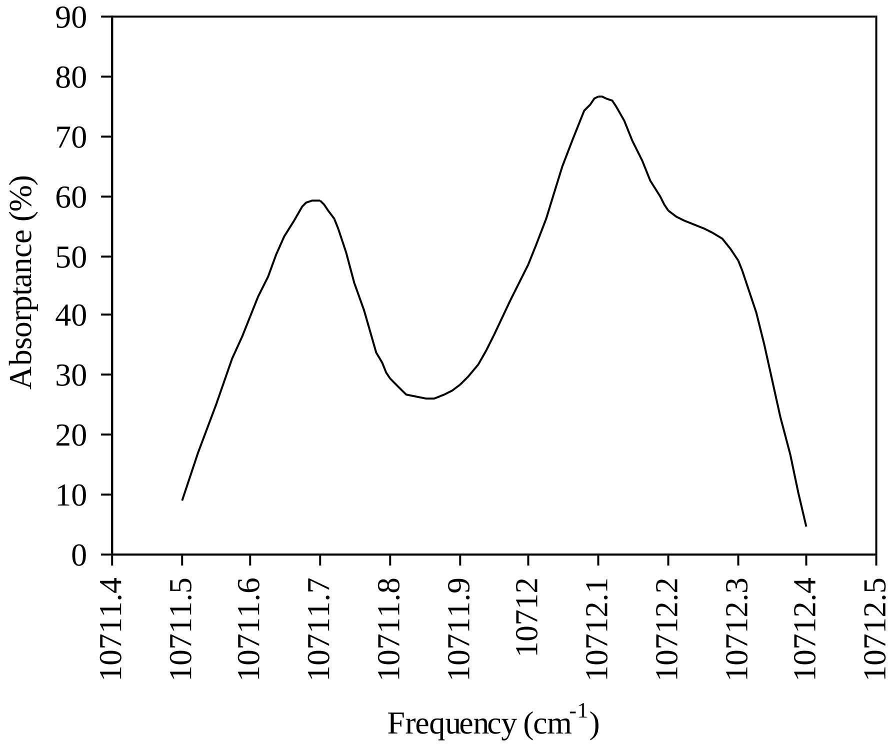

Figure 2. Absorptance of a 9335 Å Ti:sapphire laser beam for a 0.1 pr-cm path length of water vapour.

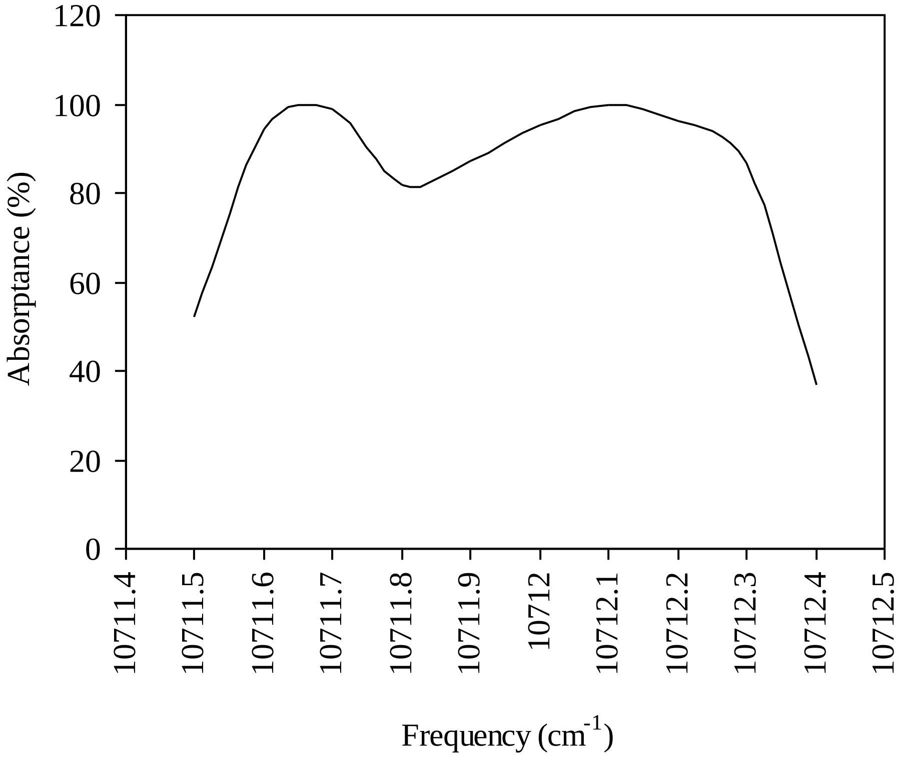

Figure 3. Absorptance of a 9335 Å Ti:sapphire laser beam for a 1.0 pr-cm path length of water vapour

Table 1. High resolution absorption lines of water vapour affecting the propagation of a 9335 Å laser beam.

Line No.	Frequency (cm^{-1})	Intensity
1	10711.5928	0.59
2	10711.6939	0.68
3	10711.7392	1.00
4	10711.9248	0.59
5	10712.0421	0.48
6	10712.0888	0.56
7	10712.1415	0.42
8	10712.2446	0.42
9	10712.2998	0.44

Table 2. Absorptance for a Ti: sapphire laser beam of wavelength 9335 Å in water vapour

Frequency (cm^{-1})	Absorptance (%) for path lengths 0.01 pr-cm	0.1 pr-cm	1.0 pr-cm
10711.5	0.94	09.07	51.98
10711.6	5.99	39.85	94.51
10711.7	10.6	59.37	98.95
10711.8	4.21	29.52	81.67
10711.9	3.46	28.55	87.11
10712.0	7.85	48.67	95.45
10712.1	13.98	76.62	99.98

10712.2	9.72	57.52	96.34
10712.3	8.09	49.28	86.64
10712.4	0.36	04.84	36.88

3. Results and conclusion

The results of our calculations for the near infrared absorptance around 9335 Å for 0.01, 0.1 and 1.0 pr-cm thickness of water vapour are presented in Table 2, and shown in Figures 1, 2 and 3, respectively. A close look at the figures reveals that the smaller the amount of the absorber the more marked is the variation. This is, perhaps, expected, as with greater amounts of the absorber the absorptance values tend to saturate. All the lines mentioned in the Table 1 contribute to the absorptance values; the main contributions are as follows. The peak around 10711.7 cm^{-1} is caused by the lines #2 and #3 — the strongest lines in the spectrum — while the biggest peak around 10712.1 cm^{-1} is caused by the line #6, closely flanked by lines #5 and #7 on both sides. The effects of the lines #8 and #9 manifest in the prominent ‘hump’ at 10712.2 - 10712.3 cm^{-1}. The lines #1 and #4 give rise to barely noticeable shoulders at 10711.6 and 10712 cm^{-1}, respectively, especially in Figure 3. Thus we see that the experimental data taken for this work agree well with the results. This concludes that the quasi-random model for simulating the intensity distribution by grouping the lines in a given frequency interval works reasonably well. In this work, a tunable Ti: sapphire laser beam is considered at the wavelength 9335 Å. The broadening of the lines is assumed to be homogeneous, as the rotational lines are observed to be very fine. Therefore, there is a scope to generalize the model for inhomogeneous broadening as well. There is clearly a scope to apply this work in atmospheric optics. The scopes of error in this computation are (a) the size of the small intervals, δ, as mentioned in the method of calculation, and (b) the number of divisions taken in the Simpson-rule-based program, which is known to any programmer.

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