ABSORPTION OF CALCIUM-VAPOR LASER RADIATION BY WATER VAPOR

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The absorption coefficient of water vapor was experimentally measured at the line of calcium-vapor laser radiation of 5.54 μm. *The absorption coefficient is studied as a function of the atmospheric temperature and humidity. The laser radiation frequency was tuned by* 0.09 cm^{-1}, *and the dependence of the absorption coefficient on laser radiation frequency was found. The calcium-vapor laser is proposed for atmospheric humidity measurements.*

INTRODUCTION

Measuring water vapor content is often important in many technological processes and is a traditional problem of meteorology. Absorption of infrared radiation by water vapor enables humidity measuring devices that can measure humidity in hard-to-reach and remote volumes, as well as continuously measure humidity in space and time.

As known, the fundamental water vapor absorption band with the center at 6.3 μm is most intense and broad. In the vertical column of the atmosphere, this band completely absorbs the solar radiation over a 5.5–7.5-μm range. Continuous and pulse laser radiation in this optical range can be used for high-sensitive humidity measurements. In the list of known laser transitions, the calcium- and strontium-vapor lasers emitting at the wavelengths of 5.54 (frequency of 1802.73 cm^{-1}) and 6.45 μm, respectively, have attracted particular attention. Based on data from Ref. 4, we calculated the water vapor absorption line profile with the center at 1802.48 cm^{-1}, which is presented in Fig. 1 (the arrow points to the position of the calcium-vapor laser radiation line). It was determined that the contribution of the weak line at 1802.54 cm^{-1} into the absorption is three orders of magnitude lower. Therefore, the line at 1802.48 cm^{-1} can be considered to be the only one.

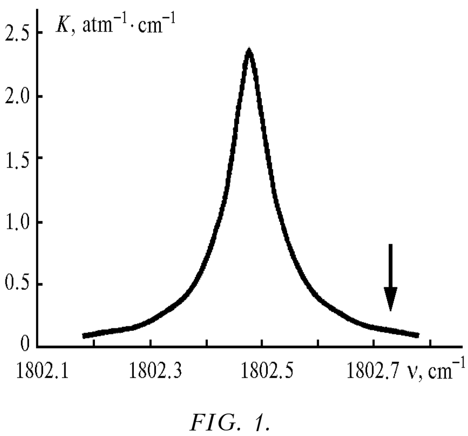

FIG. 1.

High power[1,2] and feasibility to obtain both pulse and continuous generation[1–3] are the advantages of calcium- and strontium-vapor lasers.

In this paper, continuing the earlier published ones Refs. 3 and 5, we present the results of investigation into the absorption of calcium-vapor laser radiation by water vapor, including the case of laser frequency tuning by a magnetic field.

EXPERIMENTAL SETUP AND THE RESULTS OBTAINED

We have developed two experimental setups. The first one was used for determination of absorption coefficient at 1802.73 cm^{-1}. Here we used a multimode non-tunable calcium-vapor laser. The second setup used a single-mode single-frequency laser tuned by a magnetic field.

The setup for determining the absorption coefficient for laser radiation with the frequency of 1802.73 cm^{-1} by water vapor consists of a calcium-vapor laser with a 1-m long cavity and a gas-discharge tube filled with He + H_2 mixture and metal calcium chips,[3] a beam-splitting plate of barium fluoride, a measurement cell 20 mm in diameter and 1000 mm in length placed inside a heating oven, and two identical pyrodetectors.

The laser radiation was split by the plate. The reflected beam was used as a reference one, and the beam passed through the plate and the cell was used for measurements. The two identical pyrodetectors recorded the radiation and sent the signals to the measuring amplifier. The pyrodetectors were calibrated after blowing dry argon through the cell. Then the cell bottom was covered with water, and the radiation passed above it. The measurements were carried out several minutes after the cell was filled with water, when, according to Ref. 6, the thermodynamic equilibrium may thought as taking place and the humidity is near 100% at room temperature and the atmospheric pressure. The absorption coefficient was determined by the Bouguer law for unit partial pressure

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of water vapor and unit length. The absorption coefficient at the wavelength of 5.54 μm was found to be equal to 0.13 ± 0.02 atm^{-1}·cm^{-1} at the temperature of 20°C, the atmospheric pressure, and relative humidity of 100%.

We have also measured the dependence of the absorption coefficient on temperature in the cell. Under cell heating, both the temperature and the water vapor concentration increased, whereas the total pressure remained atmospheric and relative humidity was 100%. To realize these conditions, we waited for the thermodynamic equilibrium in every measurement.

Figure 2 presents the dependence of the laser radiation absorption coefficient (K, atm^{-1}·cm^{-1}) on water vapor partial pressure (P_w, atm) and temperature (t,°C) simultaneously at the total atmospheric pressure. The closed rectangles show the absorption coefficient variations at each temperature value and water vapor partial pressure in different series of measurements. An increase of the absorption coefficient is connected with the increase in the lower level population[4] with increasing temperature, as well as with intensification of the intermolecular interactions due to increasing concentration of water vapor.

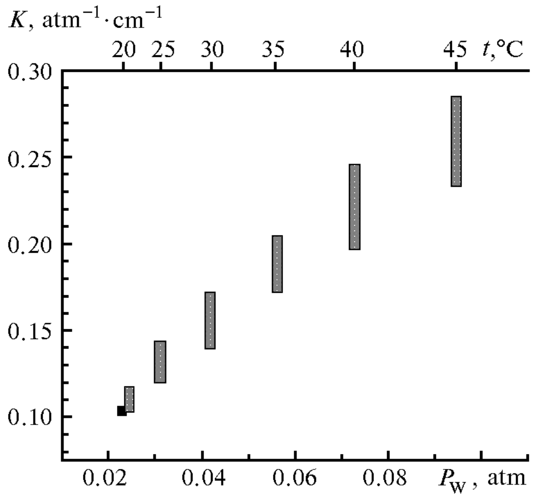

FIG. 2.

So, when using the calcium-vapor laser for atmospheric humidity measurements, it is necessary that preliminary, under laboratory conditions, one measures the absorption coefficients at different temperatures and the same water vapor concentration and at different water vapor concentration while fixed temperature.

The experimental setup for measuring the dependence of the water vapor absorption coefficient on the calcium-vapor laser radiation frequency consists of a laser inside a solenoid, a quarter-wave (λ/4) mica plate, a polarizer (a germanium plate cut at the Brewster angle), a beam-splitting plate of barium fluoride, a testing cell for water vapor, two pyrodetectors, and an oscilloscope. In this case, we used a single-mode single-frequency laser with the cavity 200-mm long and a gas-discharge tube 15 mm long with windows perpendicular to the tube axis. An opaque cavity mirror was fixed on the piezoceramics. By varying the voltage applied to the piezoceramics from 0 to 900 V, we could change the cavity length by 4.5 μm.

The radiation from the laser placed in a magnetic field was separated into the σ^+ and σ^- components with the λ/4 plate and the polarizer. Then we used only one component. The part of the radiation reflected from the splitting plate was directed to the pyrodetector. The signal from the pyrodetector came to the vertical amplifier of one oscilloscope beam and serves as a reference one. The residual radiation passed through the measurement cell to the pyrodetector, and the output signal from the detector came to the vertical amplifier of the other oscilloscope beam. The voltage, synchronous to that across the piezoceramics changing the cavity length, was fed to the sweep circuit of both beams. In measurements, the cavity length has been tuned next to the laser line shifted by the magnetic field. The technique for obtaining the calcium-vapor laser radiation frequency-tunable by using the magnetic field is considered in detail in Ref. 5.

The transmission was determined as the ratio between the radiation intensity after blowing the cell with dry argon and the radiation intensity in the cell with water vapor at 100% relative humidity and temperature of 22°C. The absorption coefficient was determined by the Bouguer law.

The dependence of the absorption coefficient (K_ν, atm^{-1}·cm^{-1}) on the laser radiation frequency (ν, cm^{-1}) is presented in Fig. 3 by dots. The arrow corresponds to not tuned laser radiation line. The tuning magnitude is shown along the x axis to the left and to the right. The solid curve presents the same dependence, but calculated by the variance formula for the single line with the center at 1802.48 cm^{-1} and the intensity of 536.999 cm^{-1}/(g·cm^{-2}) (see Ref. 4) for the curve segment from 1802.685 to 1802.775 cm^{-1}.

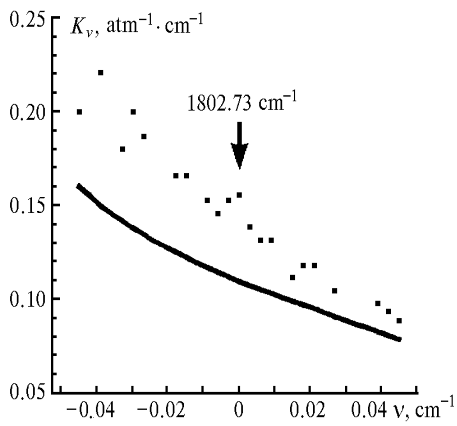

FIG. 3.

It follows from the Fig. 3 that as the radiation frequency is tuned by 0.09 cm^{-1}, the absorption coefficient changes almost twofold and its spectral behavior agrees well with the single Lorentz absorption line. When shifting the experimental points to the absorption line center by 0.03 cm^{-1}, they perfectly fall on the calculated curve.

CONCLUSION

Thus, the absorption of the calcium-vapor laser radiation by water vapor is measured. The laser radiation absorption coefficient is determined as a function of temperature and water vapor concentration in the cell at the atmospheric pressure. The frequency dependence of the absorption coefficient was obtained in the range from 1802.685 to 1802.775 cm^{-1}.

REFERENCES

1. W.T. Walter, N. Solimene, M. Piltch, and G. Gould, IEEE J. Quantum. Electron. **QE–2**, 474 (1966).
2. A.N. Soldatov and V.I. Solomonov, *Gas-Discharge Lasers on Self-Restricted Transitions in Metal Vapors* (Nauka, Novosibirsk, 1985), 149 pp.
3. V.M. Klimkin, V.E. Prokop'ev, and S.S. Monastyrev, Pis'ma Zh. Eksp. Teor. Fiz. **20**, No. 4, 251–253 (1974).
4. N.S. Benedict and R.F. Calfee, *Line Parameters for the* 1.9 *and* 6.3 μm *Water Vapor Bands*, ESSA, Prof. Paper (1967).
5. V.M. Klimkin and P.D. Kolbycheva, Kvant. Elektron. **4**, No. 8, 1818–1821 (1977).
6. B.M. Yavorskii and A.A. Detlaf, *Reference Book of Physics* (Nauka, Moscow), 260 pp.