Observation of continuous coherent emission in methane at $\lambda = 3.39$ μm in spatially separated fields

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The interaction of two standing waves separated by a distance L with a rarefied gas is investigated. For the first time ever, observation of a new phenomenon is reported, namely continuously coherent emission produced at a distance $2L$ from the first field. The emission is due to transport of the polarization by the moving particles to large distances. The radiation intensity has a sharp maximum at the center of the line, with a width inversely proportional to the time of flight of the particles between the fields. The experiments were performed in methane at $\lambda = 3.39$ μm ($F_2^{(2)}$ line).

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1. It was recently demonstrated[1,2] that in principle it is possible to obtain resonances when an ensemble of atoms interact with optical fields that are separated by large distances. In that year, several independent groups reported observation, for the first time, of absorption resonances in separated optical fields[3–6] for atoms with short lifetimes. Attention was also called[6] to the possibility of obtaining coherent radiation in a gas in spatially separated optical fields. Figure 1 hows the setup for the observation of this phenomenon. Low-pressure gas interacts resonantly with two standing waves of frequency ω, separated by a distance L. At low gas pressure, coherent radiation is produced at the center of the line at a distance $mL (m = 1,2,3\cdots)$ from the second beam. n the present paper we report the observation, for the first time ever, of this phenomenon on the $F_2^{(2)}$ line of methane ($\lambda = 3.39$ μm).

2. The experimental setup is shown in Fig. 2. Coherent emission in separated fields (CESF) was observed in a methane-filled absorbing cell with the aid of a laser spectrometer. The spectrometer consisted of a frequency-stabilized He–Ne/CH_4 laser with a narrow emission line ≈ 10 Hz, a unable laser 3, and an auxilliary heterodyne laser 2. The operating principle of the spectrometer

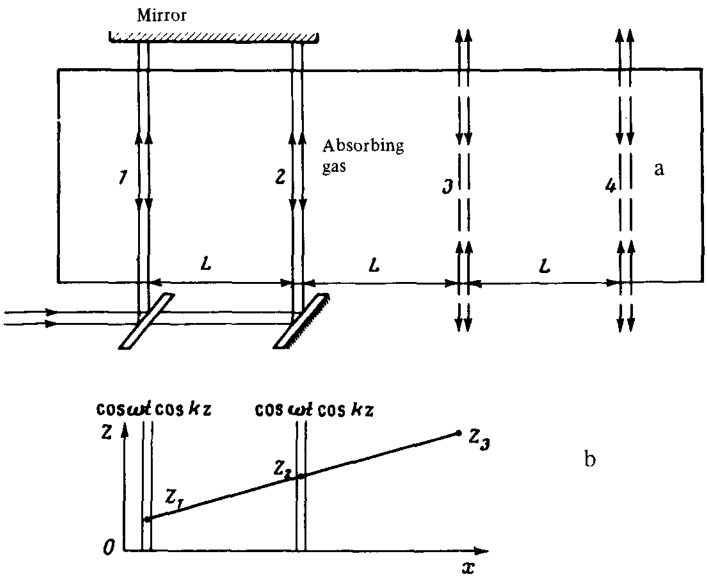


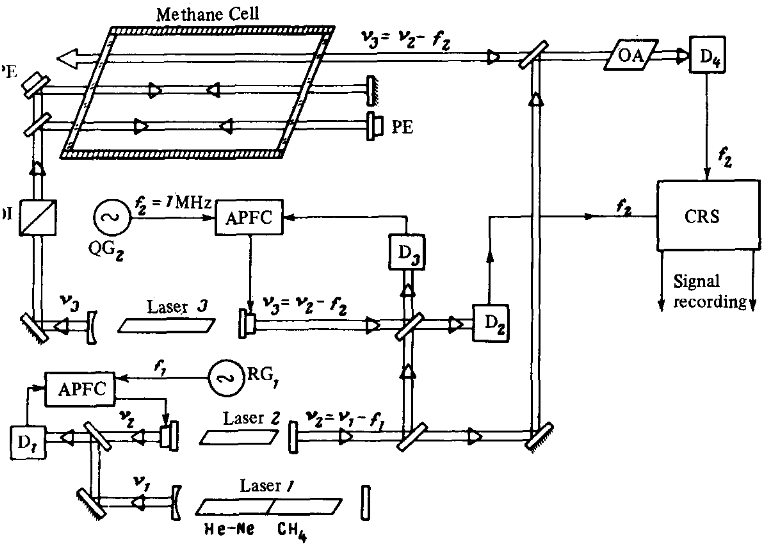
FIG. 1. Setup for the observation of the coherent emission in spatially separated fields: 1,2—standing waves, 3,4—coherent emission.

was described in detail in[7] The emission of the typical laser 3 with linewidth ≈ 10 Hz was directe to the absorbing cell, where two standing waves, parallel accurate to $\sim 1'$, were produced with th aid of mirrors. The light-beam diameter was ≈ 1 cm. The distance between beams was 3.5 cm. Th absorbing cell was 115 cm long. The methane pressure in the cell was $\sim 10^{-4}$ Torr. We registere coherent radiation produced at a distance 3.5 cm from the second beam in a direction parallel t the beam.

An estimate of the CESF intensity shows that for methane, under the conditions of ou experiments, the intensity of the coherent radiation is $I \sim 10^{-15}$ W. Direct registration of so weak signal was impossible, for the lack of photoreceivers of high sensitivity. We therefore effecte coherent heterodyne reception with the aid of laser 2 whose emission frequency was tuned away MHz from the frequency of the tunable laser. The heterodyne-laser emission power was 10^{-3} W The beats between the coherent emission and the emission of laser 2 were recorded, after synchrc nous detection at the frequency 1 MHz, with an x-y recorder as a function of the frequency of th tunable laser 3. The maximum recording-system sensitivity attained in the experiment was $\sim 10^{-}$ W.

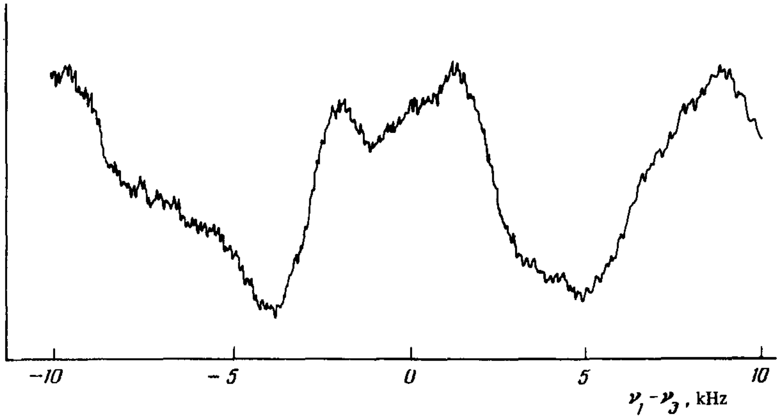
Figure 3 shows an experimental plot of the intensity of the coherent emission in methane a the tunable-laser frequency is varied relative to laser 1. Three fundamental components of th magnetic hyperfine structure (MHFS) of the $F_2^{(2)}$ line of methane are seen. The half-width of th resonance of an individual MHFS component was ~ 2.5 kHz.

Considerable difficulties in the recording of the weak signal of coherent radiation in methan were due to the inconstancy of the phases of the optical signals at the input of the photodetecto (D_4). This led to variation of the amplitude and phase of the recorded emission signal, an consequently to a distortion of the shapes of the recorded resonances. The correction for the phas difference of the optical signals was effected by readjusting the mirrors mounted on the piezc ceramic elements, as seen in Fig. 2.[1)]



IG. 2. Experimental setup: APFC—automatic frequency-phase control of the frequency, G$_1$—tunable radiogenerator, QG$_2$—quartz-controlled generator, D—photodetector, OA—opti-al amplifier, OI—optical isolater, PE—piezoceramic cell, CRS—coherent-reflecting system.

3. The observed CESF phenomenon is based on transport of the polarization of the medium to distance $2L$ from the first beam.[1] In accordance with Maxwell's equations, polarization gives ise to coherent emission. After interacting with the first field [see Fig. 1(b)], the atoms have a ipole moment at the field frequency, and a phase corresponding to the field phase at the point z_1. t large distances from the beam, owing to the spread of the particle velocities v_z, the spatial armonics of the polarization is disturbed. When the atoms interact with the second field of the tanding waves, the phase $\phi = \mp 2kz_2 = \pm 2kv_z L/u$ (u is the transverse velocity of the atoms) of the ipole moment which is nonlinear in the field experiences a jump due to the two-photon absorption nd emission of photons from waves traveling in opposite directions. The phase jump depends on



IG. 3. Plotted signal of coherent emission on the $F_2^{(2)}$ line of methane. Methane pressure 100 Torr, distance between light beams 3.5 cm, beam diameter 1 cm.

the velocity v_z and causes the appearance of a spatial harmonic of the polarization at the distanc $x=2L$.

The onset of continuous coherent emission in separated optical fields has a number o important and interesting properties. It takes place at the field frequency. The emission intensity i proportional to the square of the number of excited particles and is a rapidly varying function o the field frequency detuning from the center of the transition, with a width inversely proportiona to the time of flight of particle between the fields, this being due to the interaction of the particle with the standing wave. If the first field is a traveling wave,2) then the CESF takes the form of wave traveling in the opposite direction. The second field should always be a standing wave if a intensity resonance is to be obtained. The polarization is transported during the flight time of th particle between the beam at a velocity 10^4–10^6 cm/sec, so that the polarization and the coheren emission are delayed relative to the stimulating emission by a time equal to the time of flight. Thi constitutes an unusual coherent delay line realized in the optical band. We note that individua properties of the CESF manifest themselves in known phenomena such as superradiance, coheren resonance scattering, Ramsey resonances, and photon echo.

The indicated properties of the CESF mark it as a new, important, and interesting phenomenon for various applications and investigations. The results of an experimental investigation c coherent emission show that ultranarrow emission resonances of width $\sim 10^2$ Hz are realistic.

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1) The action of spatially separated fields is equivalent to the action of two pulsed fields separated i time by an interval equal to the time of flight of the particle between the beams. The firs observation of coherent emission in time-separated standing-wave fields in SF_6 gas at $\lambda = 10.6$ μr in the center of the spectral line was recently reported.[8]

2) At $x=2L$ there is also coherent emission at arbitrary detunings of the field frequency relative t the transition frequency, this being due to the interaction of waves traveling in the same directior The emission direction coincides with the propagation of the traveling waves.

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