Satellites induced on spectral lines of a hydrogen plasma by an intense microwave field (experimental)

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It has been found experimentally that the methods of in-resonator laser spectroscopy can be used to measure plasma waves. Previously unknown features have been found in the spectrum of a hydrogen plasma in an intense electromagnetic wave.

Research on the interaction of intense monochromatic electromagnetic fields with plasmas is attracting interest to the behavior of quantum-mechanical atomic systems in such fields. The spectra of atoms and ions are of particular interest, for possible use in the diagnostics of microwaves, both external microwaves and natural plasma waves in the microwave range. The energy spectrum of a nondegenerate two-level system in a microwave field was first studied in 1933 by Blokhintsev,[1] and the past 15 years have seen the appearance of many theoretical papers on this topic. According to a theoretical interpretation, a system of equidistant energy levels spaced at $\hbar\Omega$ arises in the field of a wave of frequency Ω. Consequently, satellites should be observed in the emission and absorption spectra of the atoms at positions shifted symmetrically from the "zero" lines (the unperturbed lines) by $q\Omega$ ($q = \pm 1, \pm 2,...$). The relative intensities of these satellites should depend on their index q and on the electric field.[2]

Attempts[3,4] to experimentally study the emission spectra of a hydrogen plasma in a microwave field have run into serious difficulties because of the effect of the form factor, the intrinsic noise of the plasma, and the low resolution and low luminosity of the spectral apparatus. The results of these experiments can be interpreted in different ways.

The situation is changed radically by switching to the highly sensitive methods of in-resonator laser spectroscopy,[5] which can be used to carry out direct measurements of the satellites that appear on spectral lines in a microwave field, to measure their relative intensities, and to determine the spectrum of plasma waves, both external waves and those that are excited in the plasma by various instabilities and nonlinear interactions. In this letter we report experiments on the absorption spectrum of hydrogen and deuterium near the α and β lines of the Balmer series in a microwave beam with a frequency of 37.5 GHz in a transparent plasma. The linearly polarized microwave radiation from a gyrotron propagates through a quasi-optical system and a lens made of a material similar to Teflon to a sealed-off glass discharge tube 8 mm in diameter, which is filled with a mixture of deuterium and hydrogen to a total pressure of 1 torr. The in-resonator laser spectrometer used in these experiments consists of a wide-band tunable pulsed laser whose active medium is an ethanol solution of an organic dye with flash-lamp pumping, along with a diffraction spectrograph with a resolution better than 10^5 constructed especially for these measurements. The length of the laser pulse, which determines the sensitivity and time resolution, is 1.5 μs; the spectral width of the output is 8–10 nm. The emission spectrum is displayed on the screen of a storage oscilloscope by means of a vidicon or recorded on film.

Figure 1 shows a representative spectrogram, recorded in a field ~3 kV/cm near the H_β and D_β lines at a discharge current of 1 A. The absorption coefficient at the

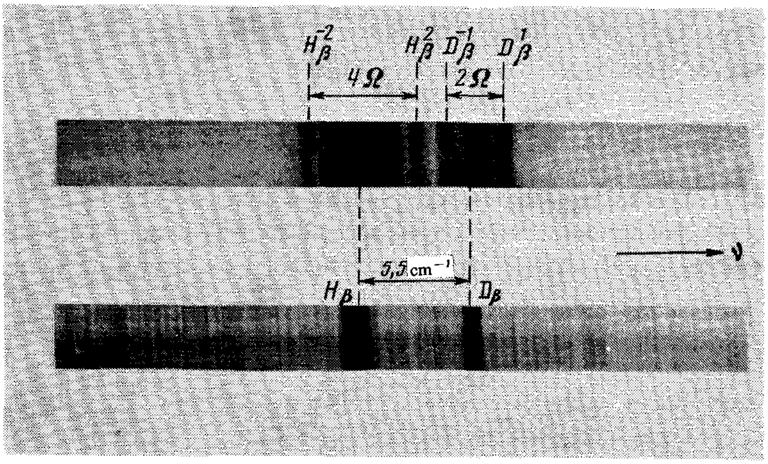

FIG. 1.

satellite frequencies is determined by the density of excited atoms in the $2S_{1/2}$ and $P_{1/2,3/2}$ states and by the cross sections for two-photon absorption (for the first satellites, with $q = \pm 1$) and three-photon absorption ($q = \pm 2$). It should be noted that the dynamic range of in-resonator laser spectrometry is limited by the cutoff of lasing when the selective loss introduced exceeds a critical level. For this reason, it is possible to measure the intensity of only one pair of satellites in a single laser pulse. However, by varying the partial pressures of the hydrogen and the deuterium, one can find a mixture in which it is possible to observe the first satellites of the lines of one component of the mixture (in our case, hydrogen) and, simultaneously, the second satellites of the lines of the other component (Fig. 1). Analysis of spectrograms of this type, their densitometer traces, and the plasma emission spectrum leads to the following conclusions: 1) The method of in-resonator laser spectroscopy can be used for quantitative measurements of the intensities of the satellites of spectral lines and to determine the spectrum of plasma waves. 2) There is a significant asymmetry of the "blue" ($q > 0$) and "red" ($q < 0$) satellites. Specifically, the intensity of the first blue satellite of the Balmer α line is three to four times that of the corresponding red satellite. This result can be interpreted well in the model of two-photon absorption and of stimulated Raman scattering with a correction for the fine structure of the H_α line. 3) The experiments show that the intensity of the satellites in the case in which the laser and microwave fields are polarized in the same direction is about an order of magnitude higher than the intensity of the satellites in the case in which the polarization directions are perpendicular. This result raises the real possibility of polarization measurements, which typically are highly sensitive and accurate. 4) The absorption of the laser beam at the satellite frequencies in two-photon processes increases the population of the upper level. The intensity of the fluorescence that results is determined by the overall absorption coefficient at the frequencies of the two satellites and can be measured by the standard techniques.[6] This procedure makes it possible to determine local values of the microwave fields, since the fluorescence signal is detected from the region in which the laser beam intersects the line of observation.

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