Anomalous Scattering of Laser Light by a Steady State Plasma

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The theory of electromagnetic scattering by a plasma developed by Salpeter [1] satisfactorily accounts for the backscatter profile of a radar from the ionosphere reported by Bowles [2]. Following the development of this theory several laboratory experiments were performed [3-7] in which the observed profiles were consistent with the theory. In this paper we report on measurements of the scattering of the plasma in a magnetically stabilized arc which show large and significant departure from the theory.

In the Salpeter theory it is shown that the shape of the profile of the scattered light is determined by the parameter α, defined by $\alpha \equiv \frac{\lambda_i}{4\pi \sin \theta/2\ \lambda_o}$ (λ_i = wavelength of the incident hight, λ_o = Debye length, θ = the scattering angle). When α is much smaller than one the correlation of the electron motion is small and a Doppler profile is predicted, when α is larger than one the correlation is large and a very narrow central peak with two symmetric satellites displaced by approximately the plasma frequency is expected. For α intermediate between the two extremes the theory predicts a sharp central peak with smooth wings extending out beyond the plasma frequency; a broad maximum occurs at approximately the plasma frequency but well defined peaks are not predicted.

In the experiment reported here a plasma is formed in a magnetically stabilized electric arc. A magnetic field of 10.8 kG is imposed parallel to the axis of a high current arc discharge. The arc is operated at an initial pressure of 10 Torr of hydrogen, the arc current being 1800 A. Temperatures of 10 eV and electron densities of up to 10^{16} cm^{-3} have been measured and reported elsewhere [8].

Light from a Q-spoiled ruby laser is focussed at a point in the plasma. The scattered light is detected by a 7265 RCA photomultiplier after passing through a rotatable interference filter (band pass 7.5 Å). The incident beam is horizontally polarized and is perpendicular to the axis of the arc. The scattered beam is perpendicular to both the incident beam and the arc axis. Thus the direction of the scattering electron density fluctuation is perpendicular to the applied magnetic field. The dimensions of the scattering volume defined by the intersection of the incident beam and the field stop of the detecting system are approximately 1.2 mm.

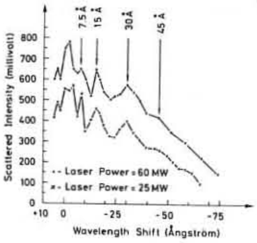

Fig. 1

In Fig. 1 the results for scattering from the centre of the discharge are shown. The most remarkable feature of this profile is the presence of satellites at 7.5 Å, 15 Å, 30 Å and possibly 45 Å. We know that for this plasma the α is about 0.4 and hence, by the Salpeter theory, no satellites should appear. To confirm that these satellites were not a result of perturbation due to the laser we repeated the experiment with higher incident power (25 MW in the first case, 60 MW in the second) and these results are also shown in Fig. 1. The position and the relative magnitudes of the satellites are apparently independent of the laser power. Although the ratio of the incident power in the two cases is 2.4, and the ratio of the Rayleigh signal from nitrogen is also 2.4, it is surprising to find that the ratio of the scattered signals is only 1.4. We therefore conclude that we cannot reliably predict the electron density of the plasma from the Salpeter theory. Note that the profile near the central frequency is apparently asymmetric.

A plasma with electron density of 1×10^{16} cm^{-3} has a plasma frequency of 8.9×10^{11} cps and if a satellite were due to the plasma frequency we would expect to find a satellite at 15 Å. This agrees remarkably well with one of the observed peaks, and the other peaks would then appear to be harmonics[+]. To check that the satellite position is dependent on the local electron density we repeated the experiment at a point 8 mm from the centre of the discharge where the electron density and temperature are smaller. The results of this experiment are shown in Fig. 2. Peaks are again observed but this time at 12.5 Å and 25 Å. A shift of 12.5 Å corresponds to an electron density of 7.4×10^{15} cm^{-3}.

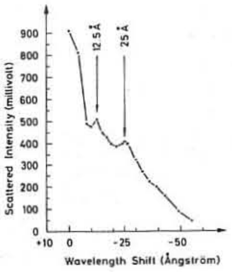

Fig. 2

The satellite peaks remind one of Tonks-Dattner resonances in which one observes enhanced scattering at approximately $\omega_p/\sqrt{2}$, $n\omega_p(n = 1,2...)$ [10]. However, Tonks-Dattner resonances require that the plasma density be non-uniform on a scale comparable to the wave length of the scattering vector. Since the scattering vector in our experiment is 4900 Å we require small inhomogeneities in the plasma to account for the observed satellites. One is led to wonder if small scale turbulence is present.
We have noted that the scattering cross section is sensitively dependent on initial external parameters such as initial pressure. More work is being done both on the scattering profile and on spectroscopic measurements in order to clarify this.

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