MAGNETIC FIELD MEASUREMENT BY LIGHT SCATTERING+)

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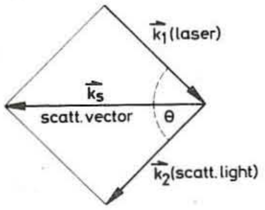
Abstract: The conditions for measuring magnetic fields in plasmas by light scattering are discussed. In experimental observations of laser light scattered by a magnetized arc plasma we have measured deviations from the normal thermal spectrum. The observed spectrum fits best with the theoretical curve due to the probe measured magnetic field.

Local measurement of magnetic fields in hot plasmas is very important. Unfortunately, the methods used hitherto have marked disadvantages, e.g. changing the plasma parameters and yielding integrated values [1]. On the other hand, laser scattering offers a possibility of locally determining magnetic fields with negligible disturbance of the plasma, in addition to the usual measurement of temperature and density. This method is based on the fact that under certain circumstances the spectrum of the scattered light is influeced by the magnetic field within the scattering volume.

In theoretical papers (e.g. [1-3]) the scattering spectrum is calculated for $B \perp k_s$ (Fig. 1). If, furthermore, $\alpha = 1/k_s D$ (D = Debye length) is lower than 1, only the electron spectrum is considered. It consists of lines whose separation equals the gyrofrequency of the electrons and whose envelope is nearly equal to the thermal scattering spectrum.



$$\vec{k}_s = \vec{k}_2 - \vec{k}_1 = \frac{4\pi}{\lambda_0} \sin \theta/2$$

Fig. 1

In this paper first we specify the conditions for measuring such a modulated spectrum. We then describe a light scattering experiment which shows the irfluece of the magnetic field in a laboratory plasma on the spectrum of the scattered light.

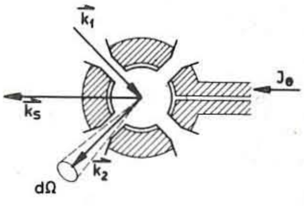
The inequality $\alpha = 1/k_s D = \frac{n}{T \sin \theta/2} \cdot \text{const} \ll 1$ (1) ensures that we have only the electron spectrum and that collective effects disappear. A second condition means that the modulation of the spectrum is well marked. This requires that the half-width $\lambda_{1/2}$ of a line is small enough compared with the separation $\Delta\lambda$ of two lines. $\frac{\lambda_{1/2\,\parallel}}{\Delta\lambda} = \frac{v_{th\,\parallel} \cdot k_s}{\lambda_c} \sim \frac{\sin \beta \ \sqrt{n}}{\alpha \ B} \text{const}' \ll 1$ (2). The half-width is determined by the Doppler shift $\lambda_{1/2\,\parallel} = v_{th\,\parallel} \cdot k_s$ which, roughly speaking, is governed by the component parallel to the magnetic field, while the perpendicular component is responsible for the envelope of the spectrum. The separation is proportional to the electron gyrofrequency. β is the mean value of the angles between $\vec{k}_s$ and the perpendicular to the magnetic field. Therefore β is a measure of the divergence of laser light as well as of inhomogeneities in the magnetic field within the scattering volume. A third condition requires that the scattered light per channel L is sufficient to keep the statistical error small: $L \sim \alpha^2 B^2 \text{const}'' \ll 1$ (3).

Conditions (2) and (3) call for large α, as opposed to (1). In accordance with the general scattering theory we may have α to about 0.5 and then get 80 % and more of the whole scattered light into the part of the electron spectrum. Then condition (2) is satisfied by electron densities of about 10^{16} cm^{-3} and magnetic fields of about 100 kG and divergence angles β of a few 10^{-2} rad. Usual scattering experiments work with β values of about 10^{-1}. Therefore, the main difficulty in our experiment lies in the small apertures and hence small scattered signals. The scattered light intensity depends only on α and B. With $\alpha = 0.5$, B = 100 kG and 100 MW laser intensity in the scattering volume, the statistical error is about 20 %. Electron temperature and scattering angle can still be freely determined, but are related by the condition $\alpha = 0.5$. Therefore there exist the possibilities

T	2	5	100	(eV)
θ	180	90	20	(grad)

. For all pairs we have the same modulation and the same scattered signals.

For a first experiment [4] we chose 90°-scattering in order to keep the stray light sufficiently small. Therefore the parameters of this experiment should be: $n_e \approx 10^{16}$ cm^{-3}, $T_e \approx 5$ eV, $\alpha \approx 0.5$. The appropriate plasma is formed in a hydrogen arc in an axiparallel magnetic field B_z. The homogeneous magnetic field of 120 kG is produced by a pulse discharge via two parallel coils (Fig. 2). The arc burns parallel to the magnetic field lines. From normal 90°-scattering we get the parameters $n_e = 1.2 \times 10^{16}$ cm^{-3},



scattering geometry

Fig. 2

$T_e = 3.2$ eV and $\alpha = 0.6$. The giant pulse of a Ruby laser is focused in direction $\vec{k}_1$ into the plasma, when B_z has reached its maximum value. We observe the scattered light emitted in the direction $\vec{k}_2$. The scattering vector $\vec{k}_s$ is perpendicular to $\vec{B}_z$. Deviations in the planes $B_z k_1$ and $B_z k_2$ originate in the apertures around $\vec{k}_1$ and $\vec{k}_2$, both 0.02 rad, in the homogeneities of B_z and the magnetic field B_θ of the arc current. In spite of these deviations we expect a modulation greater than 80 %. Fig. 3 shows the scattering spectra both with and without magnetic fields. The crosses and circles are mean values of seven discharges each. We could not measure at the laser wavelength because of excessive stray light. The curve is the best fit according to the theory of Lehner [1].

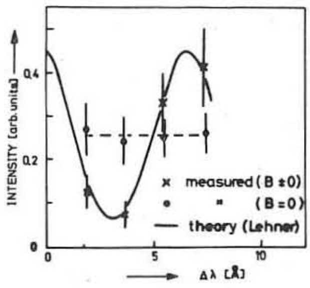


Fig. 3

From the separation of the laser wavelength and the wavelength of the first minimum we can determine the electron gyrofrequency which then gives a magnetic field of 150 ±20 kG. Deviations from an uniform modulation frequency have been calculated by Platzman et al. [5] for cases where the condition $\alpha \ll 1$ is not satisfied. With their numerical computations for cases, similar to ours, the magnetic field is lower, but by a factor less than 30%.

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