Letters to the Editor

EXPERIMENTAL OBSERVATION OF LANDAU DAMPING IN A PLASMA

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THE observation of wave damping in a collisionless plasma (Landau damping) is difficult because the phase velocity at long wavelengths is usually much greater than the thermal velocity of the particles and the damping is exponentially small; on the other hand, while short waves (wavelengths of the order of the Debye length or the Larmor radius of the plasma particles) are usually strongly damped it is difficult to excite them.

In a dense plasma in a magnetic field there is a long-wave branch of the dispersion relation (the so-called whistler mode) for which the phase velocity can be smaller than the electron thermal velocity so that a large number of resonant electrons can interact effectively with the wave and the wave damping is significant. At frequencies appreciably below the electron gyro frequency but above the ion gyro frequency the ratio of collisionless damping length l_L to wavelength λ is (cf. [1])

$$l_L/\lambda = a_1\lambda\omega_H/(2\pi)^2 v_e, \tag{1}$$

where $\omega_H = eH_0/mc$ is the electron gyro frequency, H_0 is the external magnetic field, $v_e = \sqrt{2T_e/m}$ is the electron thermal velocity, T_e is the electron temperature and a_1 is a coefficient that depends on the angle between the direction of propagation and the magnetic field (when $\theta \sim 1$, $a_1 \sim 1$). The wavelength, as in the cold plasma case, is given by the expression

$$\lambda = 2\pi\,(\omega_p^2\omega/\omega_H c^2 - \nu_r^2/2)^{-1/2}, \tag{2}$$

where ω_p is the plasma frequency and ν_r is the radial wave number.[2]

The damping length for damping due to electron-ion collisions is (cf. [3]):

$$l_c/\lambda = a_2\omega_H/2\pi\nu, \tag{3}$$

where ν is the effective frequency for electron-ion collisions and a_2 is a coefficient of order unity. In a high-temperature low-density plasma the collisionless damping (1) can be much stronger than the collisional damping (3).

The excitation of plasma waves in the frequency region $\omega \ll \omega_H$ has been investigated in [4,5]. In the present work we have observed collisionless damping of these waves; this damping is found to be two orders of magnitude greater than that due to collisions.

This experimental investigation of the excitation and damping of these waves was carried out with a system that has been described earlier.[6] The plasma is produced in a glass tube (60 mm dia.) by radio-frequency currents that flow in an exciting coil. This coil has four sections connected in opposition and produces a spatially periodic magnetic field with period $\lambda_0 = 15$ cm. The radio-frequency generator is pulsed ($\tau = 1$ msec) and operates at 10 Mc/sec. The generator power is 300 kW.

The discharge tube is located at the axis of a long solenoid (15 cm dia, length 150 cm) which produces an essentially constant magnetic mirror configuration.

The investigations were carried out in helium in the pressure range 2×10^{-3} to 5×10^{-4} mm Hg. The plasma density, measured with a microwave interferometer, was $n_e = 4 - 8 \times 10^{13}$ cm^{-3} with essentially full ionization. In contrast with ion cyclotron waves,[6] the resonance excitation of the waves considered here occurs at a magnetic field $H_0 = 1000$ Oe, in good agreement with the dispersion relation given in (2) for the indicated plasma density, frequency, and period of the excitation coil.

The magnetic field H_0 in the region in which wave propagation and damping are studied is somewhat smaller than in the excitation region and does not vary along the plasma cylinder. The measurements are carried out in this uniform field section. The wavelength in the propagation region is 9 cm and the measured damping length is $l = 40$ cm. The electron temperature is determined by measuring the relative intensities of the He lines at 4921 and 4713 Å and is found to be $T_e \sim 30-50$ eV. The damping length due to collisions, as follows from (3), $l_c \sim 10^4$ cm, a value that is 200 times greater than the experimentally measured value of 40 cm. The damping length due to collisionless damping, in accordance with (1), $l_L \sim 100$ cm; this value is in good agreement with the experimentally measured value.

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SMALL-ANGLE PROTON-PROTON ELASTIC SCATTERING AT 6 *AND* 10 GeV

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PRELIMINARY results of a study of the elastic small-angle pp scattering at 6 and 10 GeV have been published earlier.[1] The experimental method has been discussed in detail in [2].

The experiment was carried out using the proton synchrotron of the Joint Institute for Nuclear Research. The internal beam of the accelerator traversed a large number of times a polyethylene film 3 μ thick. The target was suspended on nylon threads 20 μ thick. The dimensions and the thickness of the target film were selected for best angular and momentum resolution. From the same considerations, we used an emulsion placed three meters from the target as the detector of the recoil protons. The angular resolution amounted to $\pm 1.5 \times 10^{-3}$ rad. The whole path of the recoil protons from the target to the emulsion was in vacuum.

Characteristic range distributions of secondary particles for various values of $\theta_{\mathrm{c.m.s.}}$ are shown in Fig. 1 for 10 GeV primary beam energy. The sharp peaks correspond to elastic pp scattering. The main source of the background are slow particles produced as a result of the interaction of primary protons with carbon nuclei in the target. As can be seen from the figure, the signal-to-noise ratio varies from 0.07 to 1.0 for a recoil proton momentum variation from 280 to 56 MeV/c. In order to determine the density of the recoil proton flux it is necessary to subtract the spectrum of the background particles from the total spectrum observed at a given angle θ_{lab}, which is the angle of emission of the recoil proton with respect to the primary beam. The spectrum of background particles was carefully studied at various angles using the same emulsions.

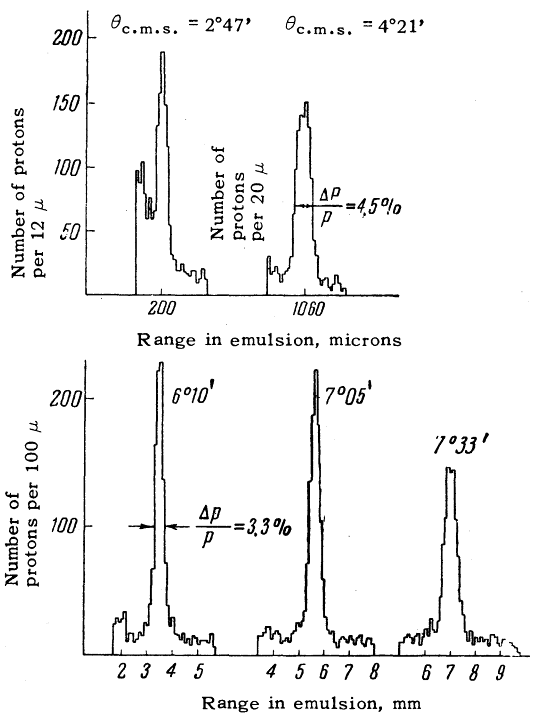

FIG. 1

It should be noted that the large resolving power of the method used almost completely excludes a contribution of the quasi-elastic scattering by bound nucleons of the nucleus. This is brought out by kinematic calculations of the quasi-elastic scattering and by experiments on the quasi-elastic scattering of protons on nucleons in the nucleus.[3]

In the experiment we have obtained the relative form of the differential cross section. The measurements were carried out with an error of 4.5–7.5% and were based on 22,000 scattering events. At 10 GeV the cross section was measured at 12 points in the angle interval $1.5° < \theta_{\mathrm{c.m.s.}} < 7.5°$. The corresponding interval of the squared four-momentum transfer is $0.0038\ \mathrm{GeV}^2/c^2 < t < 0.081\ \mathrm{GeV}^2/c^2$. At 6 GeV analogous measurements were carried out in the angle interval $1.5° < \theta_{\mathrm{c.m.s.}} < 9°$.