INVESTIGATION OF OBLIQUE MAGNETIC-SOUND WAVES OF LARGE AMPLITUDE

V. D. Rusanov and V. P. Smirnov

Submitted 2 August 1965

Large-amplitude waves, propagating in a plasma at an angle to the magnetic field, were investigated by several workers [1-3]. The first attempt to observe oblique shock waves was made in [4]. In the present paper, which is a development of investigations of linear oblique magnetic-sound waves [5] (sometimes called whistles), we investigate the transition to nonlinear waves.

Large-amplitude oblique waves were excited by a shock circuit of 15 Mc frequency. The magnetic field $\tilde{H}_z$ in the center of the loop, which was 30 mm long and 45 mm in radius, increased to 800 Oe within 2×10^{-8} sec.

A diagram of the setup is shown in Fig. 1. The magnetic field in the homogeneous part of the solenoid ranged from 200 to 2000 Oe.

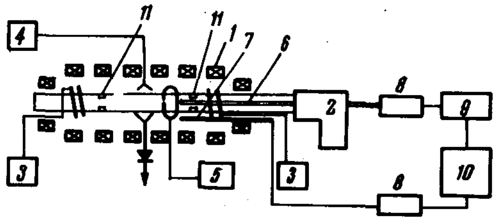

Fig. 1. Diagram of setup.

1 - Magnetic-field solenoid; 2 - vacuum system with discharge volume; 3 - high-frequency generator; 4 - microwave diagnostics system; 5 - shock circuit; 6 - measuring probe; 7 - starting probe; 8 - delay line; 9 - amplifier; 10 - oscilloscope; 11 - diaphragms.

In the course of operation, hydrogen gas was admitted to a chamber of inside diameter 2a = 78 mm, producing a pressure from 3×10^{-4} to 2×10^{-3} mm Hg. The ionization was by means of two high-frequency generators. The density was monitored in this case by the cut-off of a signal of wavelength $\lambda = 8$ mm; and after rapidly switching off the generators, the monitoring was by means of an 8-mm interferometer. The inhomogeneity of the density distribution, determined with the aid of double electric probes, did not exceed 20%. The probes, the diamagnetic pickup, and the attenuation of the neutral-atom beam all lead to an electron temperature between 10 and 20 eV. The ion temperature, estimated from the contours of the H_β and He-I lines, was close to 4 eV.

The $\tilde{H}_z$ component of the wave field was measured with the aid of a magnetic probe which could be moved along the chamber axis. The pass band of the receiving system was 50 Mc. The propagation of the wave was investigated as a function of the density (in a range 10^{12} - 1.7×10^{13} cm^{-3}), as a function of the intensity of the constant magnetic field H_0, and also as a function of the parameter $q = \tilde{H}_{z\,max}/H_0$, where $\tilde{H}_{z\,max}$ is the maximum value of the magnetic field of the circuit in the center of the loop (r = 0) in the absence of a plasma. It must be noted that on the periphery, where r = a, the ratio $\tilde{H}_{z\,max}/H_0$ exceeds q by a factor 1.5. The wave may therefore change appreciably in amplitude near the loop.

The measurements were made for values of q between 0.2 and 1.7, the distance z from the center of the loop to the magnetic probe ranging from 0 to 40 cm. It was noted that for small values of q, the magnetic field of the wave $\tilde{H}_z$ and the excitation field in the gap between the loop and the plasma have essentially the same form. However, pulsations can be seen on the

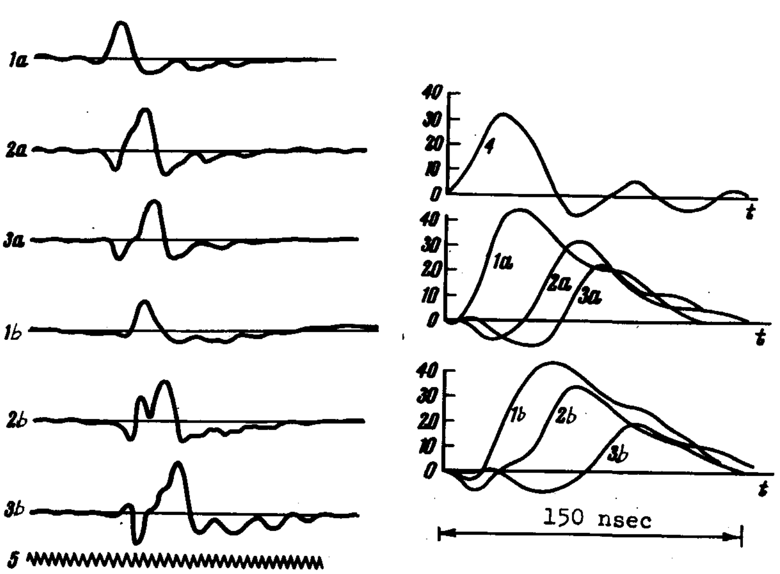

Fig. 2. Oscillograms of the derivative of the wave magnetic field (left) and their integrals ($n = 1.7 \times 10^{13}$ cm^{-3}, $H_0 = 350$ Oe) (the integrals are expanded in relative units).

leading front. The vibrational structure of the leading front is particularly pronounced at appreciable values of q. For large q, the wave in the plasma at $z < 2a$ produces a disturbance with a magnetic field which is predominantly unidirectional. The peculiarities of the wave structure at different distances from the circuit are shown in Fig. 2. Here 1a - $d\tilde{H}_z/dt$ and $\tilde{H}_z$ for $z = 0$, $p = 20$ dB, $q = 0.9$; 1b - $d\tilde{H}_z/dt$ and $\tilde{H}_z$ for $z = 0$, $p = 25$ dB, $q = 1.6$; 2a - $d\tilde{H}_z/dt$ and $\tilde{H}_z$ for $z = 4$ cm, $p = 15$ dB, $q = 0.9$; 2b - $d\tilde{H}_z/dt$ and $\tilde{H}_z$ for $z = 4$ cm, $p = 20$ dB, $q = 1.6$; 3a - $d\tilde{H}_z/dt$ and $\tilde{H}_z$ for $z = 7$ cm, $p = 15$ dB, $q = 0.9$; 3b - $d\tilde{H}_z/dt$ and $\tilde{H}_z$ for $z = 7$ cm, $p = 15$ dB, $q = 1.6$; 4 - $\tilde{H}_z$ for $r = a$, $z = 0$; 5 - $f = 100$ Mc (p - signal attenuation coefficient at the input to the receiving system).

The characteristic spatial dimensions of the oscillations on the front, calculated from the oscillograms, correspond approximately to the formula $c/\Omega_{0i}(\pi/2 - \theta)$, where c is the velocity of light, Ω_{0i} the ion Langmuir frequency, and θ the angle between the propagation direction and the constant magnetic field.

We confirmed experimentally the influence of the wave magnetic field on the wave propagation velocity. In particular, the ratio of the velocities of the compression and rarefaction waves is close to $(2H_0 + \tilde{H}_{max})/(2H_0 - \tilde{H}_{max})$.

We investigated the dependence of the maximum wave magnetic field on the maximum excitation field. When $z < a$ the dependence is nonlinear, which for large q can be attributed essentially to the nonlinear absorption mechanism. We note that for the conditions of our discharge, the wave can be regarded as collisionless up to a time interval of 10^{-7} sec. This condition is satisfied near the contour. However, at distances $z > 3a$, for $n_e = 1.7 \times 10^{13}$

cm^{-3} and H_0 = 350 Oe, spreading causes the characteristic time of the wave to reach (2 - 3) x 10^{-7} sec. In this case the collisions can affect the damping. In the region $4a < z < 6a$, where the spreading can be neglected, the wave damping length is 8 cm, and the ratio of the maximum magnetic field of the wave to the constant magnetic field is 0.2 in this experiment.

Measurements show that the damping decrement of the circuit increases with increasing q. When q = 0.8 and $n_e = 1.7 \times 10^{13}$ cm^{-3}, 20% of the initial energy of the circuit is transferred to the plasma. In the afterglow mode, the plasma density increased after operation of the circuit. The electron energy lost to additional ionization corresponds, within the limits of accuracy, to the circuit loss. Preliminary measurements, made at a density close to 10^{12} cm^{-3}, point to the presence of soft x-rays emitted from a target located at an intermediate radius of 14 cm from the exciting loop.

We have observed thus in the experiments oblique non-stationary waves with nonlinear propagation and damping. For the limiting values of the parameter q, such waves are similar in structure to the oblique shock waves.

The authors are indebted to E. K. Zavoiskii for continuous interest in the work and to Yu. G. Kalinin for participating in the work.

[1] Vedenov, Velikhov, and Sagdeev, Nuclear Fusion 1, 82 (1961).
[2] V. I. Karpman, ZhTF 33, 959 (1963), Soviet Phys. Tech. Phys. 8, 715 (1964).
[3] K. W. Morton, Phys. Fluids 7, N11, p. 1, 1800 (1964).
[4] Iskol'dskii, Kurtmullaev, Nesterinikh, and Ponomarenko, JETP 47, 774 (1964), Soviet Phys. JETP 20, 517 (1965).
[5] Kovan, Patrushev, Rusanov, Smirnov, and Frank-Kamenetskii, Conference on Plasma Physics and Controlled Thermonuclear Fusion, Salzburg, 1961, p. 205.

MELTING CURVE OF ANTIMONITE UP TO 1500 kg/cm² PRESSURE

V. A. Kirkinskii and A. P. Ryaposov
Institute of Geology and Geophysics, Siberian Division, USSR Academy of Sciences
Submitted 3 August 1965

Interest in investigations of melting under pressure has increased recently, especially in connection with the discovery of extremal points on the melting curves of several metals. Maxima were found to exist on the curves of rubidium [1], cesium [2], barium [3], and tellurium [4]. Enough data are available by now on the laws governing the melting of sulfides and their analogues.

The melting of antimonite (stibnite) - one of the most abundant antimony minerals (Sb_2S_3) - was investigated in a super-high-pressure multiplicator with double mechanical support. The apparatus was based on the multiplicator design described in [5]. The pressure-transmitting medium was a siloxane liquid. The pressure was measured with a manganin resistance manometer accurate to ±100 kg/cm². A heater with a titanium container for the investigated substance