SOME DATA ON THE ROTATIONAL MAGNETO-MECHANICAL EFFECT IN A LOW-PRESSURE PLASMA

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The previously discovered rotational magneto-mechanical effect in a low pressure plasma [2] is investigated quantitatively. The dependence of the torque in the plasma on the magnetic field strength, pressure, and type of gas and on the current flowing through the plasma is also established. The rotational magneto-mechanical effect has also been detected in an inert-gas plasma produced by a high-frequency field.

A longitudinal magnetic field produces a torque in a low pressure plasma. This has been predicted theoretically [1] and detected experimentally [2]. In the present work a quantitative investigation of this effect has been carried out.

1. METHOD OF MEASUREMENT IN A DC PLASMA

The low pressure plasma in inert gases (He, Ne, Ar, Xe) was produced in a vertical cylindrical glass tube by passing an electric current through the gas, parallel to the axis of the tube. The electrodes at both ends of the tube were fitted with heaters and activated so as to enable the direction of the current in the tube to be reversed.

The tube containing the plasma was placed in longitudinal magnetic field H (degree of uniformity not less than 97%) which was produced by passing direct current through two coils (see Fig. 1). There was a small gap between the two coils through which a beam of light could be passed. The direction of the magnetic field was checked with a compass. The magnetic field was made approximately coaxial with the tube by choosing the dimensions of the coils and tube (a 6 mm gap was left between the coils and the wall of the tube, with an over-all length 600 mm), and by making the electrodes of the tube symmetrical about the vertical axis. Better coaxial alignment was effected by screw adjustment of the table on which the lower coil was supported.

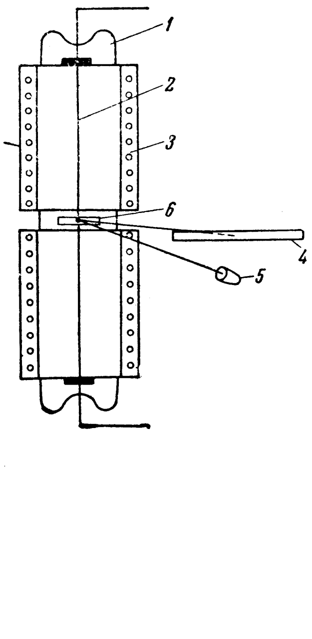

FIG. 1. Diagram of experiment. 1 – tube, 2 – fiber, 3 – coil, 4 – scale, 5 – light source, 6 – suspended system.

To measure the torque, a vertical rectangular mica wafer with a mirror in the center, was mounted in the tube. The wafer was glued to a thin quartz fiber (600 mm long and 30μ in diameter) which was fastened at each end to the base plates of the tube. A light beam from a lamp was passed through the gap between the coils and reflected from the mirror on to a measuring scale. The angular deflection of the wafer was measured by means of the mirror, lamp, and scale. The scale was at a distance of 900 mm from the mirror. The moment M of the forces acting on the wafer was determined from the angle of rotation φ, of the mica plate:

$$M = C\varphi = \frac{\pi^2 K}{T^2}\varphi, \qquad (1)$$

where C is the torsion constant, K the moment of inertia of the suspended system about the axis of rotation, and T is the period of free oscillation of the suspended system. In our experiments T = 1.4 sec and $K = \alpha m r^2 = 3.75/12$ g-cm^2 ~ 0.3 g-cm^2, where α is a coefficient, m the mass of the suspended system, and r the radius of gyration; therefore $C = 1.5 \times 10^{-2}$. On the other hand

$$M = 1.5\cdot 10^{-2}\cdot\varphi = 7.5\cdot 10^{-3}\Delta/l, \text{ dyne cm} \qquad (2)$$

where Δ is the deflection on the scale and l is the distance from the scale to the mirror.

For each experiment, check experiments were carried out and consisted of reversing the direction of the field (when the effect reverses sign) and the direction of the current through the plasma (when the effect does not reverse sign). The values of M were measured many times and averaged over all the measurements (between 3 and 5 measurements of each value were made for each direction of the current and field). The mean measuring error did not exceed 20%.

2. RESULTS OF MEASUREMENTS IN THE DC PLASMA

The dependence of the size of the magneto-mechanical moment on several parameters has been determined. Figures 2a and 2b show the dependence of the value of M on the field strength for different pressures p in argon at a current

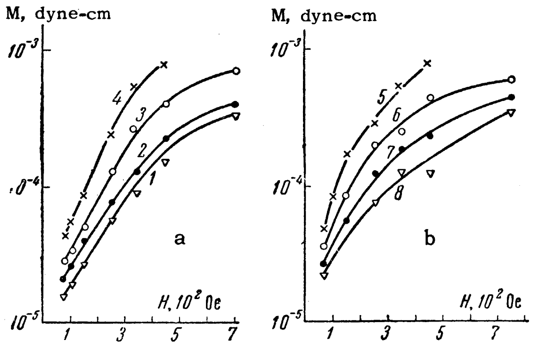

FIG. 2. Plots of the magneto-mechanical moment versus magnetic field strength in argon for various values of neutral gas pressure, p, in mm Hg: 1 – 0.31; 2 – 0.28; 3 – 0.235; 4 – 0.14; 5 – 0.094; 6 – 0.077; 7 – 0.047; 8 – 0.031.

I_a = 0.2 A. M increases with H over the range through which H is varied (up to 750 Oe) for the given values of pressure p. In Figs. 3a and 3b the relationship M = f(H) is plotted for various values of p in neon (I_a = 150 mA). Here the magneto-mechanical effect also increases with increasing magnetic field strength. The dependence of the magneto-mechanical moment in argon on the pressure p of the neutral gas is presented in Fig. 4, and the dependence on the current in Fig. 5. The dependence of M on pressure p passes through a maximum at one and the same pressure, p = 0.110 mm Hg, for different values of H. The dependence of M on the current strength shows an increase as the current increases in the given conditions. Obviously this is associated with the fact that the magnitude of the magneto-mechanical moment depends on the concentration of charged particles.

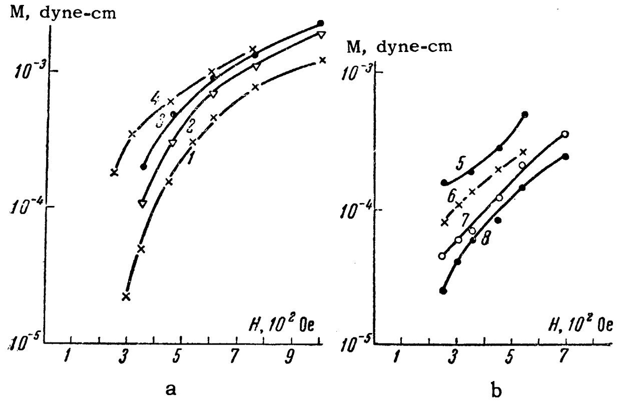

FIG. 3. Plots of the magneto-mechanical moment versus magnetic field in Ne for various values of neutral gas pressure, p, in mm Hg: 1 – 0.325; 2 – 0.275; 3 – 0.235; 4 – 0.15; 5 – 0.085; 6 – 0.049; 7 – 0.039; 8 – 0.033.

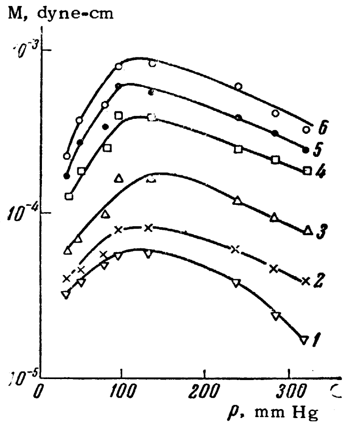

FIG. 4. Plots of the magneto-mechanical moment versus gas pressure in argon for various values of the magnetic field strength, H, in oersted, with I = 0.2 A: 1 – 75; 2 – 100; 3 – 150; 4 – 250; 5 – 340; 6 – 450.

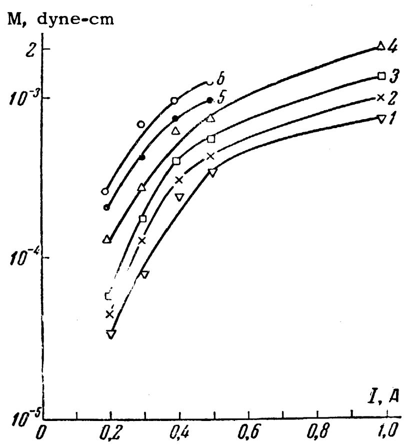

FIG. 5. Plots of the magneto-mechanical moment versus current strength in argon for various values of the magnetic field strength, H, in oersted with p = 0.047 mm Hg: 1 – 75; 2 – 100; 3 – 150; 4 – 250; 5 – 340; 6 – 450.

In order to compare the size of the magneto-mechanical effect in different gases, we have measured M in the inert gases He, Ne, Ar and Xe. The results of our measurements, carried out under the conditions p = 0.310 mm Hg, H = 75 Oe, I = 0.2 A are as follows:

Gas:	He	Ne	Ar	Xe
$M \cdot 10^5$, dyne-cm:	250	25	12	0.78

Gas	He	Ne	Ar	Xe	E/p, V·cm^{-1} (mm Hg)$^{-1}$	H, Oe
$10^3 p$, mm Hg	120	70	47	29		
$M \cdot 10^5$, dyne·cm	1.25	0.5	0.33	0.085	20	75
$10^3 p$, mm Hg	176	105	70	40		
$M \cdot 10^5$, dyne·cm	6.2	2.9	1.6	1.25	15	250

From these results it is clear that the magneto-mechanical effect for the given values of p and I_a increases drastically as the atomic number of the element is reduced.

It is also possible to compare the values of M among themselves in different gases under other conditions, namely, for identical values of the ratio E/p. Values of M for two values of E/p are compared in the table. The magnitude of E in these gases is taken from [3]. As is evident, the dependence of M on the atomic number of the element tends to decline but the rate of the decrease is much less.

3. MEASUREMENTS IN A PLASMA MAINTAINED BY A HIGH-FREQUENCY CURRENT

The magneto-mechanical effect was detected in a plasma produced by a high-frequency field (frequency ~ 1 Mc) in the longitudinal magnetic field. The experimental conditions were as follows: gas, argon (p = 0.125 mm Hg), H = 250 Oe, frequency, 1 Mc and power input about 1 kW. A magneto-mechanical effect was detected, having a moment of $M = 4 \times 10^{-5}$ dyne cm. The only check possible in this case consisted of reversing the direction of the magnetic field.

The presence of the magneto-mechanical effect in the high-frequency plasma shows that the effect under our experimental conditions is not associated with current instability and must be explained by the kinetics of the charge carriers in the plasma. A possible explanation is afforded by the transverse (Hall) diffusion of charged particles in the plasma under the simultaneous action of the radial concentration gradient and the axial magnetic field [4].

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