PLASMA OF A LIGHT SPARK IN A GAS CLOUD. DIRECTED EJECTION OF A PLASMA AND ACCELERATION OF A FIREBALL OF A LIGHT SPARK

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Optical breakdown in gases has been under intense study in recent years (see, e.g., the review [1]), and has made it possible to investigate sterile pure dense plasma. However, the presence of a surrounding gas makes it impossible to obtain very large energy-release concentrations (owing to the propagation of the breakdown [1] in a direction opposite to the laser beam) or to use the light-spark plasma in plasma vacuum devices.

In the present investigation we have obtained, for the first time, a light spark in a small cloud of gas ejected by a high-speed valve to a vacuum chamber; we investigated the features of the spark as functions of the gas pressure gradient, and also the concentration, amount, and velocity of the plasma directionally ejected from the region of the light spark because of the asymmetry of the gas-dynamic expansion and the gradient of the magnetic field. We discuss also the possibility of using such an optical-plasma gun to fill traps (such a possibility was indicated in [2]).

The experimental setup is shown in Fig. 1. The beam of a Q-switched ruby laser 1, with power 50 - 70 MW, was focused in the interior of the vacuum chamber 2 near the end of a tube serving the gas delay line. The focal length of the lens was ~4 cm.

The vacuum chamber was equipped with side windows 3 for microwave diagnostics and observation, and also with coils 4 producing a pulsed longitudinal magnetic field up to 10 kOe with amplification at the end before the spark. The high-speed valve 5, with a lightweight membrane driven by the discharge current of a capacitor, admitted within 10^{-4} sec a cloud of gas (nitrogen, argon) through a guiding nozzle into the focal zone of the lens. The gas pressure at the instant of spark development could be varied by producing a delay between the start of operation of the valve and the laser pulse (the average delay was 100 - 200 μsec), by varying the gas pressure on the valve membrane (which reached 4 atm), and by varying the position of the focus of the lens relative to the center of the cloud.

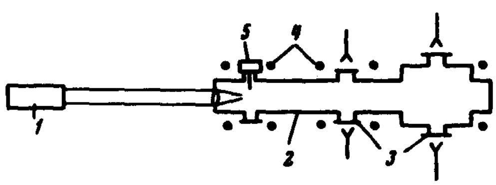

Fig. 1

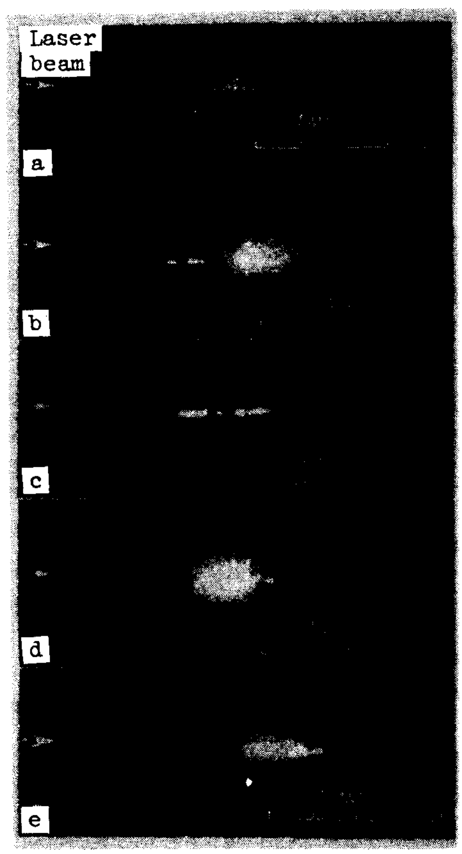

Fig. 2

Figure 2 shows typical photographs of the spark in nitrogen in the scattered laser light following a consecutive displacement of the lens to the left by 1 mm (the photograph shows a section of the tube feeding the gas with inside diameter 4 mm). One can see the decrease of the length of the spark as the focus shifts to the left closer to the front edge of the cloud. The appreciable limitation of the propagation of the breakdown opposite to the beam at very high powers should be particularly strong when the length of the spark in the homogeneous gas exceeds the width of the front or the dimension of the gas cloud. In this case all the light energy reaches the concentrated plasma near the focus of the lens and one can hope to obtain high temperatures and velocities of plasma expansion.

The ejection of the light-spark plasma can be directed so as to decrease the gas density, and by raking up a small mass it can carry away the greater part of the energy. The rate of ejection in the case of a very sharp density gradient is close to the velocity of escape into vacuum

$$u \simeq (kT_{max} Z/m_i)^{1/2},$$

and for not too sharp a gas boundary the ejection rate is [3]

$$u \simeq \{\mathcal{E}_0 / \int_0^z \rho(z)\, dV\}^{1/2},$$

where V is the effective volume of the directionally-ejected gas cone and $\mathcal{E}_0$ is the energy release.

The presence of an external magnetic field not only makes the plasma expansion nearly one-dimensional, but accelerates the plasma in the presence of a gradient of the magnetic field. The gradient force $F \approx M(t)\partial H/\partial z$, acting on the magnetic moment [4] of the induction currents of the expanding plasma of the light spark, rakes up the plasma in a direction such as to decrease the field, i.e., it is possible to accelerate and eject directionally the "fireball" of the light spark [4] by means of an external field.

For example, in the case of a strong field perturbation $M \approx -(1/2)a^3(t)H$, where a(t) is the dimension of the perturbation region for a quasispherical shock wave, $a \approx (\mathcal{E}_0/\rho_0)^{1/5} t^{2/5}$ and the plasma mass is $\mu \approx 4\pi\rho_0 a^3/3$, i.e., $z \approx F/\mu \approx 3HH'_z/8\pi\rho_0$ and $u_z \approx H_0/\sqrt{4\pi\rho_0}$ without allowance for the back pressure. With allowance for the gasdynamic back pressure $p \approx \rho z^2$ we obtain $u(t) = [M(t)H'_z/\pi a^2 \rho]^{1/2}$. In the case when the magnetic field penetrates behind the shock wave, the repulsive force acts mainly on the central hottest part, which begins to move in a zone of reduced density inside the shock wave, thereby facilitating the departure of the fireball from the shock wave. These considerations served as a basis for the attempt to observe the ejection of the plasma.

Directional ejection of the plasma was registered with the aid of microwave diagnostics at $\lambda \approx 8$ mm (critical concentration $n_e \approx 10^{13}/\lambda \approx 10^{13}$ cm^{-3}). The plasma was registered by means of the overlap of the rays simultaneously through the windows at distances 10, 30, or 50 cm from the spark. Figure 3 shows oscillograms of the overlap in the window at 30 cm from the spark for two different delays between the start of operation of the valve and the laser pulse. The left-hand tooth a corresponds to the induction from the current in the valve, the narrow pulse b is the laser pulse from the photomultiplier, and c is the almost-complete overlap signal. We see that a decrease of the delay time (t_{ab}) leads to a decrease of the

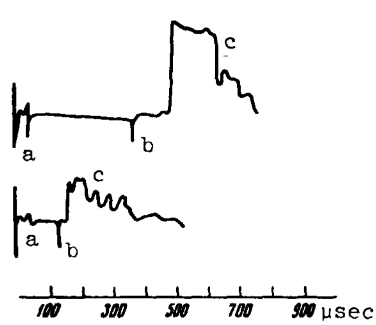

Fig. 3

plasma travel time (t_{bc}). When the delay t_{ab} is changed from 300 to 100 μsec, the plasma velocity changes from 3×10^5 to 3×10^6 cm/sec and more. For argon, the maximum velocities correspond to energies exceeding 100 eV. The particle velocities and the duration of the overlap signal ($t \simeq 100$ μsec) were used to estimate the total amount of plasma $N \gtrsim n_{cr}sut \simeq 10^{16}$ particles.

The absence of a magnetic field decreased the velocity and amount of plasma. Without a field, the plasma was not registered in the far window, but gave a noticeable signal in the middle window. Deterioration of the vacuum in the chamber, from 10^{-5} to 10^{-2} mm Hg, greatly decreased the amount of plasma arriving at the far window. The arrival of the gas front at the far window was registered by an ionization manometer after a millisecond.

The experiments performed can be used to produce and accelerate a pure hot plasma, to investigate high-temperature processes in the presence of a gas density gradient, to fill traps, to obtain fast neutrals (including excited ones), for the investigation of vacuum ultraviolet and for obtaining very high temperatures in a light spark [5 - 6], etc. Besides admission with a valve, it is possible to obtain a gas cloud by evaporating a target with a laser, but if it is necessary to work with simple or heavy types of hydrogen, a valve does not require any cryogenics and is simpler.

In conclusion, the authors are grateful to A.V. Sapozhnikov for help in constructing the apparatus.

[1] Yu.P. Raizer, Usp. Fiz. Nauk 87, 29 (1965) [Sov. Phys.-Usp. 8, 650 (1966)].
[2] G.A. Askar'yan and M.S. Rabinovich, Zh. Eksp. Teor. Fiz. 48, 29 (1965) [Sov. Phys.-JETP 21, 19 (1965)].
[3] Ya.B. Zel'dovich and Yu.P. Raizer, Fizika udarnykh voln (Physics of Shock Waves), 1966.
[4] G.A. Askar'yan, M.M. Savchenko, and V.K. Stepanov, Zh. Eksp. Teor. Fiz. 59, 1133 (1970) [Sov. Phys.-JETP 32, 617 (1971)].
[5] M.P. Vanyukov, V.A. Venchikov, V.I. Isaenko, P.P. Pashinin, and A.M. Prokhorov, ZhETF Pis. Red. 7, 321 (1968) [JETP Lett. 7, 251 (1968)].
[6] P.P. Pashinin and A.M. Prokhorov, Zh. Eksp. Teor. Fiz. 60, 1630 (1971) [Sov. Phys.-JETP 33, No. 5 (1971)].

MEASUREMENT OF THE MAGNETIC MOMENT OF THE Λ^0 HYPERON

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The determination of the magnetic moment of the Λ^0 hyperon was carried out in a number of investigations [1 - 5], in which the magnetic moment was determined by measuring the angle of the hyperon spin precession in a magnetic field.

The average value of the magnetic moment of the Λ^0 hyperon, obtained in these investigations, agrees with the predictions of the theory of unitary symmetry [6, 7]. However, different variants of breaking of SU(3) symmetry cannot be chosen at the existing accuracy of the measurements.

In the present paper we present preliminary results and a new measurement of the magnetic moment of the Λ^0 hyperon.