[1] R. Miller and A. Savage, Phys. Rev. 128, 2175 (1962).
[2] S. A. Akhmanov and R. V. Khokhlov, Problemy nelineinoi optiki (Problems of Nonlinear Optics), VINITI, 1964.
[3] L. F. Johnson, G. D. Boyd, and K. Nassau, Proc. IRE 50, 87 (1962).
[4] L. F. Johnson, J. Appl. Phys. 34, part 1, 897 (1963).
[5] A. A. Kaminskii and L. S. Kornienko, Zh. prikl. spektroskop. 2, 87 (1965).

1) Johnson [4] cites the wavelength of stimulated emission of Ho^{3+} in CaF_2 with reference to an unpublished paper

2) All values of the wavelength are indicated without recalculation from vacuum.

LIGHT SPARK IN A MAGNETIC FIELD

G. A. Askar'yan, M. S. Rabinovich, M. M. Savchenko, and A. D. Smirnova
P. N Lebedev Physics Institute, Academy of Sciences, U.S.S.R.;
Original submitted 3 February 1965.

The phenomenon of "light spark," vigorous ionization of a gas induced by a flash of intense light, was investigated recently experimentally[1-3] and theoretically[4-7]. In this article we describe the first results of an investigation of a spark in the presence of an external magnetic field, which can be used both to study the development of the plasmoid of the spark by means of diamagnetic induced signals[7] and to study the interaction between the spark plasma and the magnetic fields, with an aim at confinement against spreading, acceleration in inhomogeneous fields, ejection for filling of magnetic traps[8], etc.

We used for the experiments an ordinary Q-switched laser of construction similar to that described in [9]. The external longitudinal constant magnetic field reached 10 kOe in the described series of experiments. The receiving induction coil encircled the focal region of a lens with focal length f $\simeq$ 4 cm. Different coils with N $\sim$ 2 - 20 turns and with diameter 2R = 1 - 3 cm were used.

A typical diamagnetic signal is shown in the figure (duration of the entire sweep is 5 μsec). The first pulse1) corresponds to the appearance of the diamagnetic moment of the plasmoid (the polarity of the pulse corresponds to a decrease in the flux of the coil), and the second corresponds to the cessation of current in the plasmoid. What is instantly striking is the existence of a long interval, on the order of several μsec, between the much shorter pulses of appearance and vanishing of the perturbation. This phase apparently corresponds to the existence of diamagnetic or induction currents in the plasma produced by energy release and by the shock wave. It is interesting to note that the glow of the spark plasma continues during the lifetime of this magnetic moment and possibly plays a role in the creation of the conductivity of the medium, or else characterizes its existence.

The induction signal connected with the change in magnetic moment is

$$E(t) \approx \frac{4\pi N}{c} M_1$$

where M_1 is the magnetic moment per unit length of coil diameter (when the longitudinal dimension of the magnetic moment is smaller than the coil diameter) or per unit length of the magnetic-moment region (for a quasicylindrical magnetic moment). The induction signals can reach tens and hundreds of millivolts and are easily observed.

When fields $H < 10$ kOe were used, the diamagnetic signal and its integral (which determines the moment M) were proportional to the magnetic field ($E_{max}/H \approx 10^{-5}$ V/Oe for $N \approx 10$ and $2R \approx 1$ cm). The length of the interval between the fronts of two pulses is practically independent of the magnetic field, but decreases noticeably with increase of the first pulse (i.e., the spark energy), and decreases with decreasing radius of the receiving coil.

The magnetic moment

$$M_1(t) \approx \frac{c}{4\pi N} \int_0^t E(t)dt = a(t)H_0$$

reaches its value

$$M_{ef} \approx \frac{c}{4\pi N} E_{ef} \cdot \tau_1 \approx 10^{-6} H_0$$

even during the time of the first pulse $\tau_1 \sim 0.3$ μsec.

The mechanism of formation of the long-lived magnetic moment is still unclear. If we assume that the induction currents are connected with the motion of conduction matter in a quasicylindrical shock wave or upon expansion, i.e.,

$$M \sim \frac{1}{c} j \sim \frac{1}{c^2} \sigma v r^3 H_0$$

then we must assume high values for the conductivity σ and for the velocity v of the matter (since $M_1 \sim 10^{-6} H_0$, we have $\sigma v a^2 \sim c^2 10^{-6} \sim 10^{15}$ cgs esu and even within a region of volume $a^3 \lesssim 3 \times 10^{-2}$ cm^3 this leads to $\sigma v \approx 3 \times 10^{16}$ cm/sec^2). It must then be assumed that the total magnetic moment of the plasma varies weakly within some large range of variation of the dimensions ($\sigma v r^3 \approx$ const). If we assume that an equilibrium plasma formation is produced with a lifetime on the order of several microseconds and with circulating diamagnetic or inductive currents, then to explain so long an induction-current attenuation time it becomes necessary to assume too high a long-lived conductivity for the medium. The diamagnetism is longer-lived, and is not weakened by the triple recombination, which leaves energy in an electron plasma.

We note that the succeeding "ringing" signals due to the acoustic oscillations of the coil form, induced by the compression wave from the attenuating shock wave of the spark, disappeared when a soft shock-absorbing lining was introduced, but this did not change the diamagnetic pulse. The diamagnetic pulses disappeared following insertion of a conducting tube, which maintained the magnetic flux through it constant, whereas the "ringing" due to the shock wave from the spark in the tube was registered by the external coil. The introduction of surfaces at a small distance from the spark brings the pulses closer together, probably as a result of the decelerating or cooling action of the surface on the plasma.

Data on the magnitude and lifetime of the spark-plasma magnetic moment make it possible to estimate the effect of inhomogeneous magnetic fields on the spark plasma: The total force

$$F_z \sim M(t) \frac{\partial H}{\partial z} \sim \alpha(t) \frac{\partial H^2}{\partial z}$$

determines the rate of "raking out" or ejection of the plasma - to obtain fast jets of a pure dense plasma, to fill traps, for rapid gathering of matter ionized by light for larger concentration of the released energy, etc.

The observed long life of the diamagnetic plasma makes it possible to attempt to add energy to the spark plasma with the aid of high frequency external field or longer-lasting emission from optical generators with large energy input.

We note incidentally that the system of induction coils in an external magnetic field, mounted on dielectric forms or on metal bodies surrounding the dielectrics, can be used effectively to investigate the volume oscillations induced in the bodies by local heating due to intense light flashes.

In conclusion we thank Professor A. M. Prokhorov and P. P. Pashinin for help in constructing the generator.

[1] R. G. Meyerand and A. F. Haught, Phys. Rev. Lett. 11, 401 (1963).

[2] R. W. Minck, J Appl. Phys. 35, 252 (1964).

[3] Mandel'shtam, Pashinin, Prokhindeev, Prokhorov, and Sokhodrev, JETP 20, 1344 (1965).

[4] I. K. Wright, Proc. Phys. Soc. 84, 41 (1964).

[5] Ya. B. Zel'dovich and Yu. P. Raizer, JETP 47, 1150 (1964), Soviet Phys. JETP 20, 772 (1965).

[6] D. D. Ryutov, JETP 47, 2194 (1964), Soviet Phys. JETP 20, 1472 (1965).

[7] G. A. Askar'yan and M. S. Rabinovich, JETP 48, 290 (1965), Soviet Phys. JETP 21, in press (1965).

[8] Askar'yan, Delone, and Rabinovich, JETP 46, 814 (1964), Soviet Phys. JETP 19, 555 (1964).

[9] Gvaladze, Krasyuk, Pashinin, Prokhindeev, and Prokhorov, JETP 48, 106 (1965), Soviet Phys. JETP 21, in press (1965).

1) Fast fore-pulses were observed, and were eliminated with a thin grounded slotted conducting cylinder which did not influence the signals of interest to us, namely those due to long-duration perturbation of the magnetic field.