since some of the electronic states of the ions overlap in energy the vibrational levels of the remaining states. Therefore the energy dependence of the dissociation cross sections of $O_2^+$ and $N_2^+$ ions is affected not only by their electronic excitation but also by the vibrational excitation. The latter is clearly shown in the dissociation of $H_2^+$ hydrogen ions[9] and $D_2^+$ deuterium ions.[6]

The structure shown by curve 1 in the figure agrees with the results of McGowan and Kerwin[2] in the energy region examined by these authors. The structure of curve 3 was not observed by Tikhomirov et al[1] because of the large energy intervals used in the measurements and the narrowness of the region examined (25–50 eV).

Returning to the figure, we see that at an electron energy near the potential for production of $O_2^{2+}$ ions, there is a sharp increase in the cross section for reaction (1). It is reasonable to associate this change in cross section with the appearance in the beam of highly excited $O_2^+$ ions which in a collision can break up with a high probability into two $O^+$ ions, an event which is to be expected on the basis of the energy requirements of the different dissociation processes and the Massey criterion.[10]

The cross section for reaction (2) falls with the appearance in the beam of highly excited $O_2^+$ ions, as we would also expect.

The cross section for reaction (3) does not increase, and even drops with a change of electron energy in the region near the potential for production of $N_2^+$ ions, which can serve as an indication of the absence of an appreciable quantity of highly excited $N_2^+$ ions in the beam.

The dissociation cross section for $O_2^+$ ions is considerably greater than for $N_2^+$ ions (roughly 1.5 times for electron energies up to 36 eV and 2–3 times for higher energies), which is due to the different stabilities of these ions. These ratios and the behavior of the curves in the figure change somewhat as a function of the experimental conditions 2); however the structure of the curves remains.

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1) The particles included in the brackets can have different states: positive and negative ions, excited and unexcited atoms and molecules. We have observed negative $O^-$ ions corresponding to reaction (2) whose probability is a small fraction of that for reaction (1). We did not observe negative $N^-$.

2) Thus, for example, a decrease in the time from the formation of the ions in the source to their collision with the molecules in the chamber leads to some increase in the cross sections for reactions (1) and (3) and to their convergence. This compels us to assume that the excitation of $O_2^+$ ions is preserved for a longer time than that of $N_2^+$ ions.

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# *STUDY OF THE "SPARK" PRODUCED IN AIR BY FOCUSED LASER RADIATION*

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In focusing radiation from a laser with modulated Q, beginning at some critical value of peak power, a phenomenon is observed in air which is similar to electrical breakdown in gases.[1,2] At the focus of the lens a bright luminous spark occurs, accompanied by a characteristic sharp clap very reminiscent of an ordinary electrical spark. In this letter we report some results of an experimental study of this "spark" in air.

To obtain a high power pulse we used a ruby laser with pulse modulation, described by Gvaladze et al.[3] The pulse has an approximately triangular shape with a half-width $\tau \sim 40-50$ nsec and a peak power up to 30 MW. The diameter of the beam is $\sim 12$ mm and the angular divergence $\varphi$ is $\sim 3-5'$.

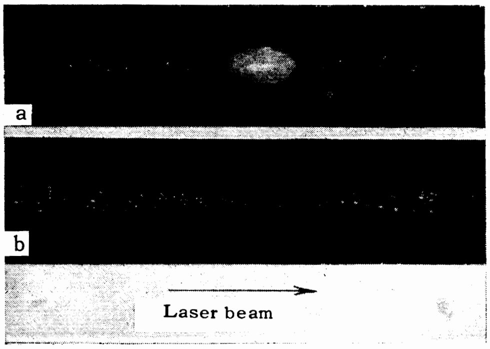

FIG. 1. Photograph of the laser beam focused by a 75 mm focal length lens: a – with occurrence of breakdown; peak power ~ 30 MW. b – below the threshold for breakdown.

The total energy in the beam is about 1.5 joules. The lenses used in the experiment had focal lengths F = 30, 75, and 210 mm.

Figure 1a shows a photograph of a spark from the laser, photographed on film sensitive to the red part of the spectrum. The spark has a characteristic spindle-shaped form extending along the beam, and has a length of the order of 10—15 mm and a diameter of a few mm. The threshold value of peak power at which the spark occurs depends on the parameters of the focusing lens and the degree of collimation of the laser beam and in our case is ~ 5—10 MW. With an increase of peak power, the size of the luminous region increases; for very high peak powers we have observed in a number of cases the breakup of the luminous volume into separate regions. In all cases in this spark a considerably brighter central region is easily visible, in the form of a thin filament extending along the optical axis of the system.

To evaluate the duration of the luminescence and to explain the dynamics of the development of the glowing cloud, we photographed the spark with a frequency of 625,000 frames per second. The photography was done with a SFR-2 high speed camera. The exposure time of an individual frame was ~ 1.6 $\mu$sec. Figure 2 shows the appearance of the photographs obtained. It is evident that the luminous region develops in the course of the first 3—5 $\mu$sec (3—4 frames) and that the main part of the radiation from the spark occurs during this period. Subsequently a collapse and cooling off of the luminous cloud occurs, accompanied by a decrease in brightness and in the dimensions of the luminous region. This stage extends for ~ 30—40 $\mu$sec. It must be mentioned that the inadequate time resolution of our photographs does not allow us to draw any conclusions about the very interesting initial stage of the discharge, corresponding to times of ~ 40—50 nsec. A determination of the shape and size of the initial volume of the spark is extremely important, since it enables us to determine the size of the region in which the energy of the laser beam is released.

To determine the total energy released in the vicinity of the discharge, we measured the fraction of the laser pulse energy which passed through the discharge region. From comparison of photographs 1a and 1b it is evident that with the appearance of a spark only a fraction of the laser light passes beyond the focus—the laser beam intensity observed by scattered light is considerably decreased beyond the spark. Appropriate calorimetric measurements showed that with the occurrence of a discharge the transmitted energy is ~ 40% of the total energy of the laser pulse. Since we do not expect strong scattering to occur in the plasma, probably about 60% of the laser energy is absorbed in the small region near the focus of the lens 1). If we assume that the initial volume in which the laser energy is deposited corresponds to the central region of increased brightness, its dimensions are $\sim 10^{-4}$ cm$^3$. Deposition of such a large quantity of energy (~1 joule) in a small volume naturally must lead to an explosive phenomenon. In the air a radial shock wave is propagated whose wave front, ionizing and heating the surrounding gas, leaves behind a cloud of glowing plasma. This hydrodynamic process of spark formation from a laser is probably similar to the process of formation of the channel of an ordinary spark discharge.[4]

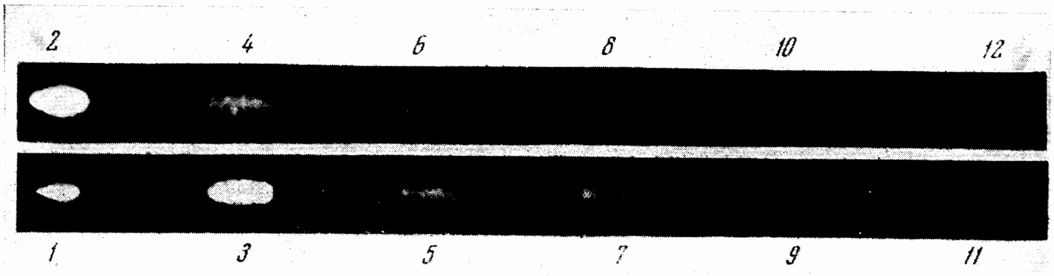

FIG. 2. Successive photographs of the development of a spark. The numbers designate the number of the frame; duration of exposure for a single frame is 1.6 $\mu$sec. The frames follow immediately one after the other.

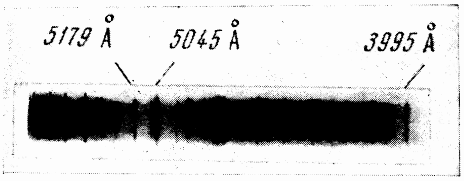

FIG. 3. Spectrum of a laser spark in air in the visible region (4000–6600 Å).

We photographed the spectrum of the laser spark, integrated over time. Figure 3 shows a spectrogram of such a spark in air in the visible region ($\Delta\lambda \sim 3900-6500$ Å). Interpretation of this spectrum showed that the observed lines belong mainly to singly ionized nitrogen and oxygen atoms N II and O II. We have also observed a line of atomic nitrogen N I and the $H_\alpha$ line of hydrogen. These lines are observed also in the spectrum of the ordinary spark discharge. However, in comparison with the spectrum of the ordinary spark, in the spectrum of the laser spark our attention is drawn to the very strong continuous background and the very large width of the observed lines—in fact, the majority of the lines are unresolved multiplets in which the distance between the individual lines is several Angstroms. Both of these facts—the strong background and the large line width—indicate a high electron concentration in the laser spark.

We made an evaluation of the quantity $N_e$ by measuring the line widths in the laser spark spectrum and in the spectrum of a spark from a standard source (a type IG-2 generator operated at $V = 14$ kV, $C = 0.02\ \mu$F, $L = 0.01\ \mu$H). According to Mazing[5] the average value of $N_e$ in such a source is $1.5 \times 10^{17}$ cm$^{-3}$. The measured half-widths of the N II line $\lambda = 3995$ Å in the laser spark spectrum and in the IG-2 spectrum are 10 and 0.8 Å, respectively, which gives a value of $2 \times 10^{18}$ cm$^{-3}$ for the electron concentration in the laser spark. A direct evaluation of $N_e$ carried out using the formulas of Vaĭnshteĭn and Sobel'man[6] for the N II lines $\lambda = 3995$ and 5045 Å ($\gamma \sim 8-10$ Å) gives a value $N_e \sim 2-3 \times 10^{18}$ cm$^{-3}$.

We also evaluated the temperature of the laser spark from the relative intensity of the N II lines $\lambda = 5179$ and 5045 Å. The line $\lambda = 5179$ Å is a superposition of two multiplets, some of whose components are unresolved. The transition probability for the entire group of unresolved components was calculated from the formulas of Bates and Damgaard.[7] Experimentally we measured the total area under the line. In view of the large errors in photometric measurements and in calculation of the transition probabilities by an approximate method, the accuracy of the temperature determination in this case is quite poor. The value of $T_e$ obtained by this method is 30,000–60,000°K. It should be emphasized again that the spectra obtained are integrated over time. The values of $N_e$ and $T_e$ obtained by us must apply to the already developed stage of the discharge in which the main part of the light is produced. By this time, as can be seen from Fig. 2, the spark already occupies a considerable volume ($\sim 10^{-1}$ cm$^3$). In the initial moments when the volume occupied by the spark is much smaller, we can anticipate that the electron concentrations and temperatures existing in the discharge must be substantially greater. Therefore the study of the initial stage of a laser-induced spark in a gas presents considerable interest, and research in this direction will be continued.

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# *ON THE SUPERFLUIDITY OF NEUTRON STARS*

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THE problem of neutron stars has recently provoked very considerable attention. The reasons for this are, first, current research into gravitational collapse, which for a star with sufficiently small