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EXPERIMENTAL STUDIES OF THE DYNAMICS OF LONG-LIVING LUMINOUS OBJECTS FORMED AT CONDITIONS SIMILAR TO THE ONES USUAL FOR OBSERVATION OF BALL LIGHTNING IN NATURE

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Summary. The paper presents the results of experimental study of the process of long-living luminous objects (LLO) formation within the decay products of water plasma, initiated by a powerful electric discharge within a jet or drop of distilled water. Such conditions are realized in atmosphere during thunderstorms, which, according to the statistics of observations, are the main cause of ball lightning. It's shown that LLO are formed in both the cases, although the formation of long-living luminous objects happens in a different way for each case.

Key words: electrical discharge, quatarons, metastable compounds, fireball.

INTRODUCTION

A discharge in water results in formation within it of a certain volume, filled with low-temperature plasma. Pressure within it is ≤ 1000 atm [Naugol'nykh, Roy]. Under the influence of this pressure, the plasma expands, pushing away the liquid and forming a cavity within it. The pressure and temperature within the cavity drop as its size increases. The plasma inside the cavity cools and recombines. The glow of the cavities is terminated long before the moment of its maximum expansion. However, under certain conditions, determined by the duration and electrical parameters of the discharge, electrode material and chemical purity of water, the glow of the cavities exists all the time of expansion and collapse of the cavern. It's not the entire internal volume of the cavity that radiates, just the luminous area, the dimensions of which are much smaller than the size of the cavity [2, 3, 4]. The time of its existence (luminescence) is almost four orders of magnitude greater than the time, energy and characteristic time of glow discharge plasma. That is why they are called long-living luminous objects (LLO).

LLO were studied both within the pulsating cavity, and after their emission to atmosphere. The studies have shown that the luminescence intensity and size of LLO do not change steadily. That is, these parameters may initially increase and then decrease or vice versa. In some cases the size and intensity of luminescence of the objects do not change during the observation time. The emission spectrum of LLO is continuous but differs sharply from the spectrum of blackbody radiation [2, 3, 4]. Examination of the long-living luminous objects within the cavity has shown that there are some events when LLO penetrated from the cavity to the surrounding water and moved within it with speed of 10 m/sec. If released into the atmosphere LLO moved with velocities ~ 20 - 50 m/s without changing their form [5]. An influence on LLO of electric (10^6 V/m) and magnetic (0.1 H) fields has not led to a noticeable change in their form, nature and dynamics of movement or luminescence. Heating of long-lived luminous objects to a temperature of ~ 800 ° C suppresses their glow. Cooling of LLO moving in the air with a metal plate having a temperature of liquid nitrogen, leads to their elongation in the direction of lower temperatures and formation of new luminous objects on the surface of the plate [5].

The results of the experiments described above suggest that the effect of formation of LLO on the one hand can not be explained by the glow of the hot electrode material, chemical reactions or clots of non-ideal plasma, the other properties of long-living luminous objects are close to the observed properties of the natural phenomenon - fireball.

EXPERIMENTAL

In the present paper we present the results of experimental studies of the dynamics of LLO formation at conditions similar to those that are realized during thunderstorms in the rain. Such a choice is made in the first place because the ball lightning is most frequently observed during thunderstorms, and secondly, due to the fact that the dynamics of LLO formation from decay products of low temperature plasma, initiated in the water, remains poorly understood. Schematic diagram of experimental setup is shown in Figure 1.

Energy release was carried out only in distilled water inside the device (1), construction of which will be discussed below (Fig. 2a). Initiation of electrical discharge was produced by a generator of high-voltage pulses (2), the amplitude of voltage which could vary from 5 to 50 kV, and the duration of which was 2 - 20 microseconds.

Integral light output from the discharge was recorded with PEM-84 (3), the signal from which was fed to the input of a dual-beam storage oscilloscope C8 - 14 (7a). Power supply of photoelectron multiplier was 1200V. When the signal from the PEM was applied to oscilloscope it generated sync pulse, which was fed to the control unit (4) of electron-optical camera (EOC) (5). The control unit was allowed to delay the beginning of shooting for the time needed for the processes under study. The EOC had been constructed on the basis of time-analyzing electron-optical converter (EOC) PIM - 103 and brightness amplifier PMU-2V. The latter allows amplifying the flux by 10^4

times. In the experiment we used only single frame shooting, in which the EOC can take 9 frames. Exposure of any frame could be varied in the range from 30 ns to 100 microseconds, the time interval between frames could change from 50 ns to 200 microseconds.

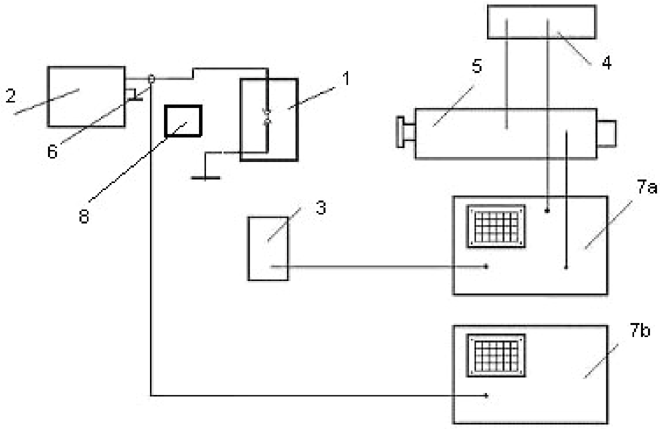

Fig. 1. Experimental setup for studying the dynamics of formation of long-living luminous objects
1 - working chamber, 2 - high-voltage pulse generator, 3 - PEM-84, 4 - control unit and the synchronization of the EOC, 5 - electron-optical camera, 6 - Rogowski loop; 7 - Dual Beam Storage Oscilloscope, 8 - a source of penetrating pulsed illumination.

The discharge current was measured using a calibrated Rogowski loop (6), the signal from which was fed to a second two-beam storage oscilloscope C8 - 14 (7b). Using two oscilloscopes was necessary because of different time spans in which the currents were recorded (time of energy release <10 microseconds) and the dynamics of LLO formation (~ 1 ms). The signal from the Rogowski loop allowed to control power characteristics of the discharge. The control of EOC was conducted with supplying pulses that control EOC shutter to the second input of the oscilloscope 7a. Oscillograms of the pulses and signals from the PMT allowed to compare the nature of the integral after-discharge luminescence and dynamics of the formation of long-living luminous objects. If necessary, we could use source of discrete penetrating illumination, its work was synchronized with EOC's shutter-pulses.

In the first series of experiments the discharge was carried out inside the jet of distilled water that had a speed of 2 m/s and diameter of 8 mm. Electrodes were placed along the jet axis, as shown in Figure 2a. In the second series plasma was formed within a droplet with diameter of 3 mm, which was stringed on electrodes - picture in Figure 2b.

The photo, shown in Figure 2b, is made with electron-optical camera immediately before discharge. Exposure of frame - 5 microseconds. For visualization of drops we used sequential lighting. In addition to the electrodes and droplet on the photo 2b reflection from the sidewall of the working chamber and a comet within water, which moved upwards and overlapped discharge gap was visible. In this case, the flux of ultraviolet radiation didn't fall on the photocathode of the EOC.

Breakdown voltage in the experiments was $2 \cdot 10^4$ V, the time of main energy release - 5 microseconds, the maximum current - 3500A, energy, accumulated by capacitor - 25 J.

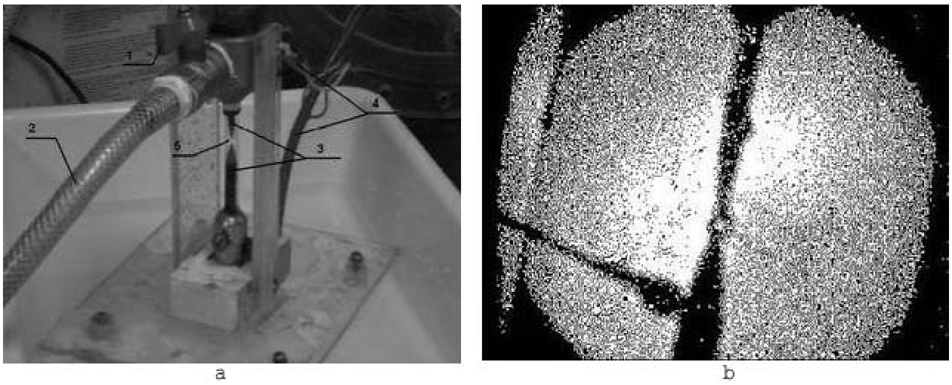

Fig. 2. Photos of the device for the implementation of the discharge in a jet of distilled water (a) and droplet located between the electrodes (b). 1 - valve, 2 - flexible hose for water supply, 3 - electrodes, 4 - cable for feeding high-voltage pulse, 5 - water jet

THE RESULTS OF THE EXPERIMENT

Figure 3 shows oscillograms of signals from the PMT corresponding to the different behavior of the decay products of the plasma initiated by electrical discharges of the same power in distilled water. The increase in flux corresponds to the deflection of the beam upwards. The marks showing moments of EOC's shutter actuation are visible.

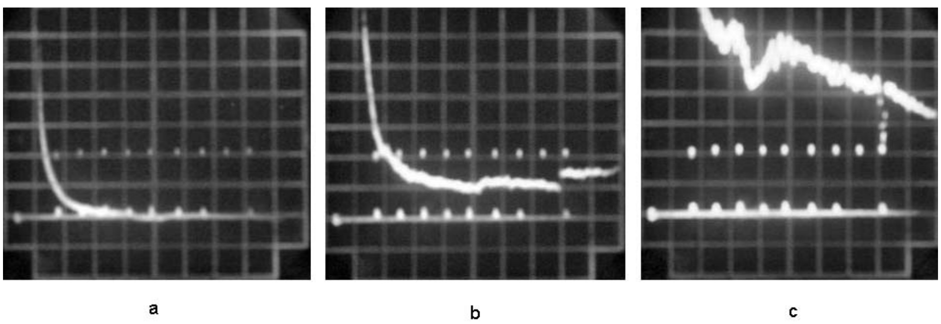

Fig. 3. Oscillograms of signals from the photomultiplier and the control pulses from the EOC. Time resolution - 200 microseconds/point

In the case where the conditions necessary for LLO formation are not satisfied, the glow of recombining plasma and products of its decay steadily decreases and ceases to register with PEM 500 - 600 microseconds after the discharge, as shown by the oscillogram in Fig. 3a. If the discharge occurs in distilled water, electrodes are made of refractory material (C, W, Mn), amplitude and temporal parameters of discharge are in the right range, then after-discharge glow takes another form, indicating LLO formation. Photographs 3b and 3c shows the two main types of the afterglow. In the first case oscillogram of the signal from the photomultiplier at the initial stage is similar to the one shown in Fig. 3a. The difference manifests itself later, when 600 - 700 microseconds after the discharge the signal ceases to diminish, remaining almost constant over the ~ 1.4 ms, and even increases abruptly. The third photograph shows another type of afterglow, radically different from the one presented in the oscillogram 3a. Oscillogram, presented in Fig. 3c, shows that in this case the signal from the photomultiplier is much greater than the signal recorded on the photo 3a. We observed local drops and growths on the background of general reduction of emission. These local changes in the signal may have big amplitude and duration (pulses in the 800 and 1600 microseconds) or small amplitude (weak oscillations of the oscilloscope beam practically throughout the time of registration).

Results of frame-by-frame shooting of dynamics of areas, the glow of which is illustrated on figures 3b and 3c, are presented in Figure 4.

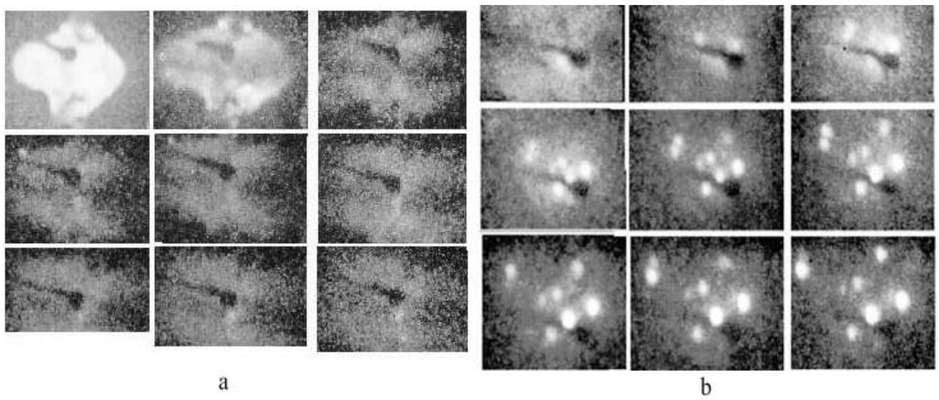

Fig. 4. Result frame-by-frame shooting of formation dynamics of long-living luminous objects, initiated by discharge in a jet. The sequence of frames from left to right, top to bottom

As we mentioned above, for suppression of ultraviolet radiation of the discharge plasma we placed copper oval plate with a maximum size of 5 mm between the channel of discharge and the EOC lens. It was fastened with copper wire with diameter 1.5 mm. This screen is located at a distance of 10 mm from the discharge gap and is visible on each frame in the form of obscure dark "comet". The vagueness of its image is due to the fact that the screen is inside the diffuse luminous clouds, formed from the collapse of water plasma.

In the first (upper left) frame of figure 4a decay products of the discharge plasma generated in the form of highly luminous oval are visible. At the bottom of the frame, as on two subsequent ones, a piece of water jet illuminated by these products is visible. The photos in Figure 4a show that the radiation intensity of the luminous clouds initially decreases (frames 1 - 3), and then remains practically unchanged. Reliable recording of LLO formation during the first 500 microseconds after the end of energy release is not observed.

The start of frame-by-frame shooting, results of which are shown in Figure 4b, coincides with the end of registration process shown in Figure 4a, and are like a continuation of it. At figure 4b one can clearly see the formation of long-living luminous objects. At first inside diffusely glowing cloud some "thickening" is formed, which then increases its brightness. Moreover, an increase in brightness may occur non-steadily (for example, an object in the upper right side of frames 5 - 9). The picture 5b also recorded the process in which the formation of LLO is accompanied by its growth. Starting with the fourth frame, almost in the center of each of it a visible luminous object whose dimensions are growing is visible. Gradually, it overlaps the image of wire that holds the screen. It means that LLO is formed between the screen and the EOC lens. Increase in the size of this glowing object can not be attributed to its movement towards the lens, for its movement to the desired length (~ 25 cm) would lead to the complete defocusing of its image on the EOC photocathode. The maximum recorded LLO size is close to the size of the plate, shielding ultraviolet (~ 5 mm). На рисунке 5 показана динамика образования ДСО в результате разряда в капле. Figure 5 shows evolution of LLO after discharge in the drop. The start of shooting is delayed in relation to the end of energy release in 200 microseconds, exposition of the first frame - 2 microseconds, of the rest of frames - 5 microseconds, and the interval between frames was 200 microseconds.

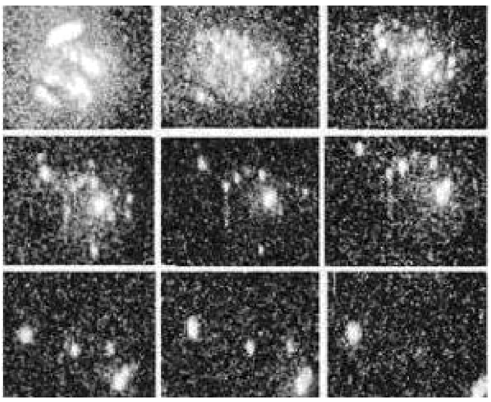

Fig. 5. Dynamics of LLO, formed as a result of discharge through a drop of water. The sequence of frames is the same as in Figure 4

The results of frame-by-frame photography, presented in Figure 5, show that in 200 microseconds after the end of energy release on the background of faint luminous clouds large luminous objects are visible. The following photographs show that some of these luminous objects disappear, and in the remaining LLO start to form. The size of some long-living luminous objects increases (the object on the left side of frames 7 - 9). Radiation of background decreases. Thus, the process shown in the photos of Figure 5, is similar to that shown in Figure 4b.

CONCLUSIONS

LLO formation from unusual weakly glowing metastable compounds, which are the product of collapse of discharge plasma, initiated in water, is characterized with long afterglow. The nature of these compounds remains unclear. Perhaps their appearance is associated with formation of water clusters – quatarons and fractal aggregation into larger objects. The formation of such structures in water vapor are specified in [6,7]. An important role can also play by metastable atoms of hydrogen and oxygen, which are formed as a result of the discharge. Their formation is evidenced by spectra of radiation of dissipating plasma [8]. Reactionary ability of the excited atoms is much higher, than of not excited ones. Hence, not excited atoms of oxygen and radicals OH will react first of all with metastable atoms. By virtue of significant affinity to electron of atomic oxygen and OH, and to small potential of ionization of metastable oxygen and hydrogen the excited molecules with ionic and not covalent linkage will be formed. The geometry of such molecules will differ from a spatial arrangement of atoms in not excited molecules. For example, atoms of hydrogen and oxygen in a usual molecule of water settle down in tops of a triangle with an angle $\angle HOH = 104.5^\circ$. Metastable atom in a state ${}_2^2S_{1/2}$ will react with radical OH just like atom of an alkali element. In such case $\angle H^*OH = 180^\circ$ [9]. Another combinations of the compound are possible, for example O^*OH, O^*O_2, H^*O_2, $H_2{}^*O_2$, $O_2{}^*O_2$, etc. Such molecules will possess a stock of energy approximately equal to energy of excitation of metastable atom. Properties of the condensed phase formed from such compounds will sharply differ from properties of water or ice. Release of energy reserved in such excited molecules can lead to fluorescence or luminescence and other effects. The question on life time of such compounds in a gas or condensed phase remains open.

These data, in addition to those in [1 - 8], indicate that long-living luminous objects are a natural product of the decomposition of low-temperature plasma of electric discharge in distilled water. This means that LLO and metastable energy-intensive compounds from which they are formed, occur at every discharge of a linear lightning when she was a channel which in any way in contact with water. The time of existence and size of such long-living luminous objects, as shown by experiments, depends on the qualitative and quantitative parameters of water-air mixture, through which the discharge and its current characteristics. Subject to certain conditions as a result of a linear lightning strike may generate large LLO, which we believe are called "fireball".

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ДИНАМИКИ ОБРАЗОВАНИЯ ДОЛГОЖИВУЩИХ СВЕТЯЩИХСЯ ОБЪЕКТОВ ПРИ УСЛОВИЯХ БЛИЗКИХ К ВОЗНИКНОВЕНИЮ ШАРОВОЙ МОЛНИИ В ПРИРОДЕ

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Аннотация. В работе представлены результаты экспериментального исследования процесса образования долгоживущих светящихся объектов (ДСО) из продуктов распада водяной плазмы, инициированной мощным электрическим разрядом в струе и капле дистиллированной воды. Такие условия реализуются в атмосфере при грозах, которые, согласно статистическим данным наблюдений, являются основной причиной возникновения шаровых молний. Показано, что ДСО образуются в обоих случаях, хотя формирование долгоживущих светящихся объектов происходит различным образом.

Ключевые слова: долгоживущие светящиеся объекты, продукты распада водяной плазмы, электрический разряд, шаровые молнии, низкотемпературная плазма.