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Ball lightning passage through a glass without breaking it

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ABSTRACT

In long history of ball lightning (BL) theory development there is a struggle of two concepts. According to the first one, BL – is a high frequency electrical discharge, burning in the air due to action of alternating electric field or a continuous current generated by an external source of energy. According to the second one, the BL is a material body, storing energy within itself. Data banks of BL observations give evidence that BL can pass through glasses, leaving no traces on them. Supporters of the first concept consider this as the proof of the correctness of the “electric field” BL nature. Representation of BL as a material body with internal source of energy explains most of its features, but has difficulties in explanation of BL penetration through glasses. We describe results of research of the glass, through which BL freely passed, that was observed by one of the authors. They proved the presence of traces left by BL. With a help of optical and scanning microscopes and laser beam probing of the glass, that experienced action of 20 cm BL, we have found traces in it: in the glass we found a region of 1–2 mm, at the center of which a cavity of 0.24 mm diameter is located. This gives evidence to a “material” nature of BL. BL possibility to pass through small holes and its ability to “make” such holes poses a number of difficult issues to researchers indicated in the article.

1. Introduction

1.1. Observations and models of ball lightning

Cases of BL observations are known since ancient times (Arago, 1838; Brand, 1923). Oddly, but in our time, the only source from which one attempts to create a model of BL, are the results of its observations. The reason is a short duration of its lifetime (no more than a few minutes), the unpredictability of its appearance and the failure of its reproduction in the laboratory. As a rule, BL is a glowing sphere of 10–20 cm in diameter, floating in air away from conductors, the movement of which is not effected by a wind (Brand, 1923; Barry, 1980; Grigor'ev, 2006; Imiyanitov and Tikhyi; 1980; Singer, 1971; Stakhanov, 1996; Smirnov, 1988; Stenhoff, 1999). It can affect a person by electric current, and at hitting of a vessel with water it is capable to heat it to a boiling temperature. On this basis, it was found that the energy density inside the BL volume can be up to 10^{10}J/m^3 (Goodlet, 1937; Stenhoff, 1999; Egely, 1993; Nikitin et al., 2014b). BL during explosion can vaporize metal objects with mass up to 20 g (Brand, 1923; Imiyanitov and Tikhyi, 1980; Bychkov et al., 2010). BL can penetrate into a room through cracks and even through the closed window (more about it is in the next section).

There are two basic approaches to creation of BL model. According to one of them, BL is a material object that stores energy within itself. According to the second, BL is electric discharge plasma cloud burning in air due to energy supplied thereto from an external source. As one of developed models of the “material” BL an “electrodynamic model” `(Nikitin, 1998, 2006b, 2014, 1999; Nikitin et al., 2014b). According to this model, BL consists of a core (with large number of small plasmoids having a positive charge) and a spherical shell of a dielectric material. Due to presence of uncompensated electric charge of a core the material of the shell is polarized, and there arises a force pulling elements of the shell toward the center of the shell. This force is sufficient to withstand the Coulomb repulsion of the core elements and the pressure caused by the mechanical movement of these elements. This force is similar to the force of a surface tension and naturally explains the presence of the spherical shape of BL.

The uncompensated electric charge of the core is the cause of BL motion under the influence of electric fields of the Earth. Like any material body, when moving the BL to be decelerated by air and blown away by the wind. However, if the strength of the Earth electric field is greater than the force of the wind, the BL will move against the wind.

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The electric charge flowing from the BL, can be the source of the corona discharge near its surface and cause formation of ozone and nitrogen dioxide (Dmitriev, 1967; Singer, 1971; Bychkov and Nikitin, 2014; Nikolaev, 2009; Nikitin et al., 2014a). At shorting of the charged core and some conductor, BL can discharge to the conductor and cause affection of people by electric shock. The movement of electric charges in the plasmoids forming the core of the BL or creation of pulsed plasma on the BL shell (Bychkov et al., 2010), can be the cause of its radiation in the optical and radio ranges. Being driven by the electric field, BL can come to the window pane and "leak" into a room through a crack or a slot (Grigor'ev et al., 1992). It can also, by spending part of its energy to heat the glass to melting and form a hole in it (Kolosovskii, 1981). Unfortunately, the "material" BL cannot pass through the glass without affecting it.

In contrast, the "field" model of BL easy copes with the task of BL passing through a glass (and, in general, through any dielectric). Indeed, energy flux of high frequency electric field or constant electric field in a certain range of wavelengths can pass through the glass with almost no loss of energy. Therefore, through the glass can pass a region with high electric field strength, in which conditions of discharge existence are supported. On the basis of these facts hypotheses appeared, according to which BL is an electric discharge, burning in air. In order to ignite the discharge in air, it is necessary to create conditions so that the rate of "multiplication" of electrons accelerated in the electric field is greater than their rate of loss due to attachment to molecules and recombination with positive ions. These conditions can be implemented in the discharge excitation in alternating or direct electric field. One option for such a "field" BL model is the model of Kapitza (1955, 1989). According to it, BL is a high frequency discharge in the antinode of the standing electromagnetic wave.

However, the search of a channel region for the discharge energy feeding was unsuccessful (it was supposed that the discharge is fed by radio emission discharges of the linear lightning). Handel and Leitner (1994) made an attempt to save the model of Kapitsa (1955) and suggested that the energy of linear lightning discharges in the intervals between pulses is stored in the vibrational and rotational energy states of water molecules, and then it is emitted in a form of atmospheric maser rays. However, estimates have shown that due to fast energy relaxation of excited water molecules in collisions with air molecules, the existence of such a maser is impossible (Nikitin, 2006a). Finkelstein and Rubinstein (1964), and Uman and Helstrom (1966) made an assumption that the channel of DC current between the cloud and the ground can for any reason to contract in cross-section in a region with high conductivity. This can lead to an increased release of energy in some limited region of space, and cause its glow. It is natural to assume that such a violation of local homogeneity of atmospheric currents often occurs near conductors (which often leads to appearance of St. Elmo's fires). In this regard, there is an interesting hypothesis of Lowke, who considered a possibility of discharge conditions realization in air in strong electric fields near the current channels in the ground after the lightning strike or near the windscreen of strongly electrified aircraft (Lowke, 1996; Lowke et al., 2012).

Enumerated hypotheses of "field" BL satisfactorily cope with an explanation of only one its property – passing through the intact glass. However, this cannot be said about other properties of the "field" BL. "Field" BL model can not explain the reason for the sphericity of BL and presence of clear boundary in it. On the contrary, the calculations (Lowke, 1996; Lowke et al., 2012) and experiments (Ohtsuki and Ofuruton, 1991) indicate no discharge of the spherical shape. This hypothesis experiences great difficulty explaining such a simple phenomenon as free movement of BL. According to Handel (Handel et al., 2004), the movement of BL is due to the beating of frequencies of two masers. According to Lowke theory, BL is able to move only at small height above the ground or near the frontal glass of a plane (Lowke, 1996; Lowke et al., 2012). However, in the majority of cases BL was observed at high altitudes and far from other conductors (Nikolaev, 2009; Bychkov and Nikitin, 2014; Sokolov, 2015). "Field" theory does not attempt to explain the cases of BL electrical hazards and a phenomenon of its large energy store (Goodlet, 1937; Stenhoff, 1999; Imiyanitov and Tikhyi, 1980; Nikitin et al., 2014b). It is limited to an explanation of energy delivery to BL maintaining its glow, comparable with the power of 100 W incandescent bulb. For hundred seconds of BL lifetime it will spent about 10 kJ of energy, while the "experimental" measured BL energy is 10^3 times greater – 10 MJ (Goodlet, 1937; Stenhoff, 1999; Imiyanitov and Tikhyi, 1980; Nikitin et al., 2014b). In view of the foregoing one can advise to researchers to carefully analyze the material of "smooth" passage of BL through the glass even when the observers say about absence of glasses change traces. It seems to us that we were the first to conduct this analysis.

1.2. Events of ball lightning penetration through glasses

The study of the BL effects on a window glass is a method to get a large amount of information needed to understand the nature of these objects. This is because of, if one can say, a special "purity" of these "natural experiments". Indeed, chemical compositions and physical properties of the glass window are practically the same in all countries of the world. The consequence of this is almost complete identity of observation descriptions of BL interaction with glasses and material results of these interactions. Quite a full analysis of the interactions between BL and glasses is presented in (Grigor'ev et al.,1992). In (Bychkov and Nikitin, 2014) were investigated cases of ball lightning interaction with glasses and their impact to glasses, and appearance of BL in modern (after 1980) and old type airplanes (total 52 cases) in closed space of their frame.

Events of BL interaction with glass can be divided into three types. The first type is the passage of a BL through existing holes and cracks, including – cracks in the glasses. The size of the holes are often by 10–100 times smaller than the diameter of the BL. BL when passing through a slot changes its shape, sometimes stretching into a filament or tape. Mechanism of BL passing through a small hole was considered in (Gaidukov, 1992). BL was considered as a material body in a flexible cover filled with elements of a small size. According to the "material" BL model described above, the force, "pulling out" BL through a crack can be action of the electric field of the Earth on the charges of BL core.

The second type is the active influence of the BL on the glass leading to the formation of holes in it. The picture of this effect can be found in the descriptions (Stakhanov, 1996), and (Kolosovskii, 1981): "In the summer of 1977 in the Moscow region Fryazino a teacher and a group of students who were in the classroom on the second floor, saw a "shaggy" glowing ball of approximately 5 cm in diameter, which closely approached the outside of the window glass. A small circular hole with glowing red edges was formed in the glass. Gradually, the diameter of the hole has increased up to 3–4 cm. After that BL flared and disappeared with a loud sound. The second (inner) window glass remained intact. The time during which the BL melted the glass was about 5 s. The glass thickness was 2.5 mm. The hole took the form of a cone, the edges were not melted. The disk, which could fall out of the hole, was not detected."

Events similar to the described have been studied in (Turner, 1997; Nikitin et al., 2006a; Bychkov and Nikitin, 2014) and have been studied experimentally (Kolosovskii, 1981; Nikitin et al., 2006a, 2011). According to the described above event, BL can have a store of energy, enough to heat the glass to its melting temperature T_m=1300 K. For heating of the glass portion volume $V=\pi \cdot 2^2 \cdot 0.25=3.14\ cm^3$ to the temperature T_m=1300 K is required energy $E=\rho \cdot V \cdot C.(T_m-T_0)$=5.5 kJ, and power delivered to the glass is $P= E/5$ s=1.1 kW. (Here ρ=2.6 g/cm^3 – density of the glass, C=0.67 J/g K – heat capacity of the glass, T_0=300 K is the initial temperature of the glass). Approximately the same values of the heat energy quantity required for the formation of a ring crack in the glass were obtained in our experiments (Nikitin et al., 2006a). We heated the samples of glass 3.7 mm thick by flat nichrome