LETTERS TO THE EDITORS

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Once again on the Gatchina discharge and ball lightning

(comments on G D Shabanov's paper "On the possibility of making natural ball lightning using a new pulse discharge type in the laboratory" [*Phys. Usp.* **62** 92 (2019); *Usp. Fiz. Nauk* **189** 95 (2019)])

M L Shmatov

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Abstract. **We show that a recent paper by Shabanov [*Phys. Usp.* 62 92 (2019); *Usp. Fiz. Nauk* 189 95 (2019)] contains several important unsubstantiated and erroneous statements. In particular, the estimate of the average ball lightning charge presented in that paper corresponds to an impossible situation with an approximately 100-fold excess of the electric field strength near the outer boundary of the ball lightning over the air breakdown field under nearly standard conditions.**

Keywords: Gatchina discharge, long-lived luminous formations, ball lightning, electric air breakdown

The recent paper by Shabanov [1] presents a detailed review of experiments on the production of long-lived luminous formations by an electric discharge over a water surface, which was called the 'Gatchina discharge'. Along with important data required for reproducing such formations and valuable information on their properties, paper [1] contains three fundamentally important but unsubstantiated statements, as well as two erroneous statements.

Shabanov asserts in Section 6 [1] that objects produced in his experiments [2, 3] and experiments by Fantz et al. [4] (in this situation, an 'object' and a 'long-lived luminous formation' are synonyms) "have a different nature" (papers [2, 3, 4] are cited in [1] as [1, 2, 29]). This statement is based on an estimate of the energy of a long-lived luminous formation [4] (which was called 'a plasmoid' in [4]) and the results of the experiment performed by Shabanov with an aluminum disk 0.1 mm in thickness and approximately 120 mm in diameter with a hole about 30 mm in diameter [1]. The disk was suspended on dielectric threads at a height of about 20 mm over a water surface used for the discharge [1]. In the presence of the disk, no long-lived luminous formation appeared, and a fused spot was observed on the disk after the discharge [1]. The fused metal mass was 2–4 mg, corresponding to "2–4 J of the spent energy" [1]. According to the estimate given in [4] for the discharge energy $E \approx 19\,\mathrm{kJ}$, the plasmoid energy E_{plasmoid} should be approximately $0.22E$. In the experiment with the disk with the discharge energy $E = 7.2\,\mathrm{kJ}$, the assumption that 22% of this energy is transferred into the luminous formation gives the transferred energy about 1.6 kJ [1]. The statement about the different nature of the objects is substantiated only by the fact that the last value considerably exceeds 1–2 J: "If [in the experiment with the disk] the luminous object had time to form, then after interaction with the release of 1–2 J, it disappears at once, not revealing the transfer of a few kilojoules" [1].

This substantiation is insufficient, first of all because the energy spent for aluminum, water, and air heating is not estimated and is not even mentioned in [1]. The disk mass was about 2.9 g. If it was heated, for example, from 20 °C to an average temperature of 100 – 200 °C, this heating alone would require approximately 210–490 J (see [5]), which exceeds the energy required to melt 2–4 mg of aluminum by at least a factor of 100.

It should also be taken into account that according to data presented in [4], the value 0.22 in experiments by Fantz et al. is in fact the upper bound for the ratio E_{plasmoid}/E and can considerably overestimate its real value; E_{plasmoid} was found by time integrating the calculated power P_{plasmoid} of the energy input into a plasmoid [4]. In this case, P_{plasmoid} was found as the difference between the total energy release rate P_{total} and the energy dissipation rate P_{water} in water estimated as $I(t)^2 R_{\mathrm{water}}$, where I is the current passing through the water and the plasmoid formation region, t is time, and R_{water} is the resistance of the water reservoir [4]. It was assumed that R_{water} is time-independent and coincides with the minimal value of the total resistance R of the circuit, approximately 88 Ω and corresponding to $t \approx 15\,\mathrm{ms}$ (the time was measured from the time of discharge onset). According to data in [4], R_{water} was mainly determined by the water resistance between two electrodes: a copper disk with a hole at the center submerged in water and a plasma cloud produced by the discharge over the water surface. The area S_{c} of the contact surface of this cloud with water depended on time [4], whereas the approximation $R_{\mathrm{water}} = \mathrm{const} \approx 88\,\Omega$ ignores this effect. As a result, a decrease in S_{c} with time after achieving the maximum value could lead to significantly underestimating P_{water} and hence overestimating P_{plasmoid} at the stage of a decrease in S_{c}. We note that for $t \approx 155$ ms, when the discharge ends and the plasmoid begins to exist independently, R is approximately $260\,\Omega$, i.e., exceeds the minimal value of this parameter chosen as R_{water} approximately threefold.

The statement "The identical behavior of luminous objects and natural ball lightning leaves no room for doubt

M L Shmatov Ioffe Institute,
ul. Politekhnicheskaya 26, 194021 St. Petersburg, Russian Federation
E-mail: M.Shmatov@mail.ioffe.ru

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about their similar nature'' in the conclusion of [1] is also unsubstantiated. First of all, the 'Gatchina discharge' has not yet produced long-lived luminous objects with lifetimes exceeding 1–2 s, whereas the lifetime of ball lightning (or, according to the terminology in [1], 'natural ball lightning') can reach at least a few tens of seconds (see, e.g., [6–9]). In addition, the volume energy density $\rho_E^{\rm bl}$ of ball lightning can reach at least a few hundred J cm^{-3}. For example, observations presented in [8] correspond to $\rho_E^{\rm bl} \geqslant 620$ J cm^{-1}. The generation of long-lived luminous objects with comparable energy densities with the help of the 'Gatchina discharge' has not been demonstrated so far.

The possible difference between mechanisms providing the existence of ball lightning and plasmoids produced by a discharge over a water surface was previously mentioned in [10].

The arguments presented above show that the conclusion in [1] also contains another unsubstantiated statement: ''the approach developed in our work has made it possible to produce an analog of natural ball lightning in laboratory conditions and thereby laid the foundations for its systematic study.''

We also note that luminous objects reproducibly produced by exciting air and existing for 1–2 s after excitation have been known since the end of the 1960s [11–15]. Their comparatively long lifetime is related to the population of the metastable states of oxygen molecules [12, 13]. The air was excited by radio waves [11–15]; the possibility of similar excitation of air by an electric discharge followed by luminescence was discussed in [12, 13].

The visual similarity of long-lived luminous objects produced by both the 'Gatchina discharge' and radio waves with ball lightning may be related to the excitation of air near the ball lightning. Such assumptions were made previously in [12, 13, 16].

Erroneous statements are presented in Section 7 in [1]. They concern the estimate of the charge Q of ball lightning (in [1], the term 'uncompensated charge' is used) and the assumption that the pressure produced by this charge is balanced by the 'pressure of the envelope of a polar dielectric' (this assumption is substantiated only by the reference to paper [17] cited as [64]). We note that in [1] and below, only the electric charge localized within the visible ball lightning boundary is considered. The possibility of a partial localization of the electric charge outside this boundary was discussed in [18] and is beyond the scope of our comment.

According to the estimate presented in [1], $Q = 4 \times 10^{-4}$ C for the average ball lightning with diameter $d = 24$ cm. In this case, the electric field strength $\varepsilon_{\rm b}$ at the ball lightning boundary would be approximately 2.5×10^6 V cm^{-1}. Under conditions close to standard ones, this value is approximately 100 times higher than the air breakdown electric field strength, which makes the long existence of the electric field of about 2.5×10^6 V cm^{-1} impossible (see, e.g., [9], where it is assumed that $\varepsilon_{\rm b} \leqslant 25.5$ kV cm^{-1}, and [19]).

In [17], an attempt was made to substantiate the possibility of stabilizing ball lightning whose main component is a sphere with a large positive electric charge Q ($Q = 3 \times 10^{-3}$ C for the sphere radius $R_0 = 7$ cm) by the external pressure produced by ''polarized water molecules gathered around the charged sphere.'' The quantitative model proposed in [17] is based on several erroneous assumptions. We consider the two main ones.

First of all, it is assumed that the polarization and hence the potential energy of water molecules are determined solely by the electric field of the charged sphere (dipole–dipole repulsion is mentioned only as an effect preventing water vapor condensation) [17]. The authors present an example in which the pressure near the outer surface of the sphere is 2.2×10^8 N m^{-2} and the temperature $T = 300$ K [17]. The concentration of water molecules for such parameters corresponds to a condensed state of matter (however, analysis of the attempt by the authors of [17] to substantiate the description of water in this region and neighboring regions as gas is outside the scope of our comment).

The second assumption is that the orientation polarizability of water molecules is $p_0^2\varepsilon/(3kT)$, where p_0 is the dipole moment of a molecule, ε is the electric field strength (denoted by E in [17), k is the Boltzmann constant, $T = 300$ K, and $\varepsilon = 5.5 \times 10^9$ V m^{-1} is the electric field strength on the outer boundary of the sphere corresponding to the ball lightning stability condition. In reality, the applicability of this description of orientational polarizability is restricted by the condition $\varepsilon \ll kT/p_0$ [20, 21], which for $T = 300$ K corresponds to $\varepsilon \ll 6.7 \times 10^8$ V m^{-1} (the value $p_0 \approx 1.855$ D $\approx 6.188 \times 10^{-30}$ C m was used [22]).

For fixed Q and R_0, the use of each of the assumptions considered above considerably overestimates the force acting on a water molecule located at a fixed distance from the charged sphere, thereby considerably overestimating the pressure of water molecules on this sphere.

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References

1. Shabanov G D *Phys. Usp.* **62** 92 (2019); *Usp. Fiz. Nauk* **189** 95 (2019)
2. Shabanov G D, in *Proc. 3rd Intern. Conf. Natural and Anthropogenic Aerosols, St. Petersburg, September 24–26, 2001*, p. 368
3. Shabanov G D *Tech. Phys. Lett.* **28** 164 (2002); *Pis'ma Zh. Tekh. Fiz.* **28** (4) 81 (2002)
4. Fantz U et al. *J. Appl. Phys.* **114** 043302 (2013)
5. Zinov'ev V E *Teplolfizicheskie Svoistva Metallov pri Vysokikh Temperaturakh* Spravochnik (Thermophysical Properties of Metals at High Temperatures. Handbook) (Moscow: Metallurgiya, 1989)
6. Dmitriev M T *Sov. Phys. Tech. Phys.* **14** 284 (1969); *Zh. Tekh. Fiz.* **39** 387 (1969)
7. Singer S *The Nature of Ball Lightning* (New York: Plenum Press, 1971); Translated into Russian: *Priroda Sharovoi Molnii* (Moscow: Mir, 1973)
8. Dmitriev M T, Bakhtin B I, Martynov V I *Sov. Phys. Tech. Phys.* **26** 1518 (1981); *Zh. Tekh. Fiz.* **51** 2567 (1981)
9. Smirnov B M *Sov. Phys. Usp.* **35** 650 (1992); *Usp. Fiz. Nauk* **162** (8) 43 (1992)
10. Stephan K D et al. *Plasma Sources Sci. Technol.* **22** 025018 (2013)
11. Powell J R et al. *Bull. Am. Phys. Soc.* **12** 751 (1967)
12. Powell J R, Finkelstein D *Adv. Geophys.* **13** 141 (1969)
13. Powell J R, Finkelstein D *Am. Scientist* **58** 262 (1970)
14. Ohtsuki Y H, Ofuruton H *Nature* **350** 139 (1991)
15. Zarin A S, Kuzovnikov A A, Shibkov V M *Svobodno Lokalizovannyi SVCH-Razryad v Vozdukhe* (Freely Localized Microwave Discharge in Air) (Moscow: Neft' i Gaz, 1996)
16. Shmatov M L *J. Plasma Phys.* **81** 905810406 (2015)
17. Zaitsev I V, Zaitsev S V *Sov. Tech. Phys. Lett.* **17** 249 (1991); *Pis'ma Zh. Tekh. Fiz.* **17** (7) 34 (1991)
18. Shmatov M L *J. Plasma Phys.* **69** 507 (2003)
19. Raizer Yu P *Gas Discharge Physics* (Berlin: Springer, 1997); Translated into Russian: *Fizika Gazovogo Razryada* 3rd ed. (Dolgoprudnyi: Intellekt, 2009)

20. Kittel Ch *Introduction to Solid State Physics* 4th ed. (New York: Wiley, 1971); Translated into Russian: *Vvedenie v Fiziku Tverdogo Tela* (Moscow: Nauka, 1978)
21. Sivukhin D V *Obshchii Kurs Fiziki* (General Course of Physics) Vol. 3 *Elektrichestvo* (Electricity) (Moscow: Nauka, 1977)
22. Malenkov G G, in *Fizicheskaya Entsiklopediya* (Physical Encyclopedia) (Ed.-in-Chief A M Prokhorov) Vol. 1 (Moscow: Sovetskaya Entsiklopediya, 1988) p. 294