

General Relativity Explains Why Ball Lightning Does Not Fall

Charles H. McGruder III

Department of Physics and Astronomy, Western Kentucky University, Bowling Green, KY, USA

Email: mcgruder@wku.edu

How to cite this paper: McGruder III, C.H. (2025) General Relativity Explains Why Ball Lightning Does Not Fall. *Journal of Modern Physics*, 16, 1222-1231.
<https://doi.org/10.4236/jmp.2025.169063>

Received: August 1, 2025

Accepted: September 8, 2025

Published: September 11, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

We suggest ball lightning does not fall because of the gravitational force experienced by ball lightning. We show that this force is predominantly determined by the electrons in ball lightning that came chiefly from the lightning strike that caused the phenomenon. General Relativity predicts that these electrons cause ball lightning to experience gravitational repulsion.

Keywords

Ball Lightning, General Relativity

1. Introduction

Ball lightning is spherical in shape and ranges in size from a centimeter to 10 meters. It is luminous and exhibits various colors such as white, yellow, red, or blue. It is associated with lightning strikes. It is a transient phenomenon that usually exists for several seconds. However, it can occasionally persist up to 10 minutes. Finally, we note it is an extremely rare phenomenon [1]-[3]. [4] cites only 5 - 15 reliable reports of ball lightning events per year.

Although ball lightning has been known for many centuries, it is one of the most mysterious atmospheric phenomena. There are many theories of ball lightning (50 - 100), but there is no consensus on which of these theories is correct if any of them is correct.

Theoretical understanding of ball lightning employing well known physics is so poor that particles have been invoked to explain ball lightning that have never been observed in laboratories such as magnetic monopoles [5] [6], black holes [7] [8], axions [9] and dark matter [10]. In addition, exotic proposals such as nuclear reactions [11] and antimatter [12] have been made. Here we do not present a model of the structure or formation of ball lightning; instead, we discuss only why

it does not fall as normal physical bodies do.

2. Theory

The motion of ball lightning is highly enigmatic because it appears to defy gravity, that is, it does not fall, rather its motion is horizontal. [13] suggests this lack of vertical motion is caused by the earth's electric field, [14] by an electric discharge that continuously varies on a microsecond time scale, [15] through trapped electromagnetic waves inside the plasma that create outward radiation pressure sufficient to counteract gravity, [16] [17] maintain a plasma contained within a force-free magnetic field, [18] electrostatic attraction between similarly charged clusters that supports ball lightning preventing it from falling, [19] a plasma-microwave structure that prevents falling, [20] a microwave-trapped plasma cavity, [21] a self-contained spherical current/radiation circuit, where energy is stored outside the ionized core that creates electromagnetic-balancing forces that allow the structure to float and [22] a phase-locked electromagnetic wave packets within plasma, which lead to stable motion without falling.

In contrast to all the above theories, we employ General Relativity, which is Einstein's theory of gravitation [23], to explain ball lightning's lack of falling motion. This theory predicts that not only mass but also energy gravitates. Specifically, we employ the circumstance that the electrostatic field energy associated with charged particles gravitates repulsively [24] to explain the observational fact that ball lightning does not fall.

We base our theory on just two fundamental assumptions:

1) Ball lightning is charged as [13] [14] [18] [25]-[27] assume.

2) Ball lightning is a physical body, meaning that it obeys the laws of physics. Therefore, it is not a hallucination or caused by sensual perception as some maintain [28] [29]. Observations show that ball lightning moves as a whole and we therefore assume that it responds to gravitational forces as a whole. Consequently, if only Newtonian gravity were present and no other forces, ball lightning would fall.

Instead of Newton's theory of gravitation we employ Einstein's theory of gravitation, which is more commonly referred to as General Relativity, to explain why ball lightning does not fall as normal physical bodies do. According to Einstein, energy gravitates, therefore, the electrostatic field energy associated with charged particles must gravitate. It gravitates repulsively [24].

The basic equation we employ in our analysis of the motion of ball lightning is [30]:

$$g_E = \frac{n^2}{m} g_e \quad (1)$$

g_E is the contribution of the electrostatic field energy to the gravitational acceleration of ball lightning. m is the mass of the matter in ball lightning in units of electron mass. n is the number of electrons in the ball lightning that predominantly originated in the lightning strike that caused the phenomenon. Technically,

n should include charged particles in the atoms or ions that may be a part of ball lightning, but we have shown [30] that their effect is extremely small, because their masses are so much higher than those of electrons. So we do not include them in n .

g_e is the contribution of the electrostatic field energy of a single electron to the gravitational acceleration of ball lightning. The effect of electrostatic field energy of an electron of mass, m_e , on the surface of the earth, on the gravitational acceleration is [24]

$$g_e = -\frac{e^2}{m_e c^2 r} g_N = -4.4 \times 10^{-22} g_N = -\frac{g_N}{n_0} \quad (2)$$

which is the classical electron radius divided by the radius of the earth, r , multiplied by $g_N = -\frac{GM}{r^2}$, the Newtonian acceleration of gravity. c is the speed of light

and e the charge of an electron. For convenience we introduce: $n_0 = \frac{1}{4.4 \times 10^{-22}}$. Below we will give a physical interpretation of n_0 .

Combining Equations (1) and (2) leads to:

$$g_E = -\frac{n^2}{mn_0} g_N \quad (3)$$

It is most important to understand the following. Because $g_N < 0$, that is, physical bodies fall downward, according to the above equation g_E , the gravitational acceleration of the electrostatic field energy, is upward. Thus, the energy of the electrostatic field gravitates repulsively [24].

In general, n and m of ball lightning on the right side of Equation (1) are not known. However, we do know the value of g_E on the left side of Equation (1). Since ball lightning does not fall it means that:

$$g_E = -g_N \quad (4)$$

This equation means that the upward gravitational acceleration caused by the electrostatic field energy of the electrons, which came chiefly from the lightning bolt that created the ball lightning, balances the normal Newtonian gravitational acceleration.

Combining these last two equations yields:

$$\frac{n^2}{m} = n_0 = 2.3 \times 10^{21} \quad (5)$$

So, even though we generally do not know the values of n and m , we do know the ratio of $\frac{n^2}{m}$. We now turn to employing the above equation to explore the relationship between the values of n and m under various circumstances.

2.1. Electron Body

A number of theories propose that electrons play a major role in the formation and structure of ball lightning: [18] [31]-[37].

In this section we consider the extreme case that ball lightning contains only electrons. m in the above equation is expressed in units of electron mass. It follows that for an electron body $m = n$. We refer to the value of n in this case of an electron body as n_0 . The above equation yields $n_0 = 2.3 \times 10^{21}$ electrons in an electron body that exactly balances gravity. If n is greater than n_0 , then the electron body will accelerate upward. If n is less than n_0 , then it will accelerate downward.

Lightning bolts are generally in the range of 5 to 350 coulombs, which corresponds to 3×10^{19} to 2×10^{21} electrons. Thus, n_0 is approximately in the highest part of the range of normal lightning strikes. Consequently, if ball lightning is a pure electron body, it would mean that its occurrence is rare, which is indeed the case.

According to General Relativity the gravitational acceleration, g_B , that ball lightning experiences is the sum of Newtonian acceleration plus the contribution to the acceleration due to the electrostatic field energy of its charges.

$$g_B = g_N + g_E \quad (6)$$

Assuming that ball lightning consists only of n electrons, **Figure 1** shows the gravitational acceleration of ball lightning in units of $|g_N|$ as a function of $\text{Log}_{10}(n)$. $g_B = 0$ means that the ball lightning is neither rising nor falling, which corresponds to observations. $g_B > 0$ means it is rising and $g_B < 0$ falling as normal bodies do.

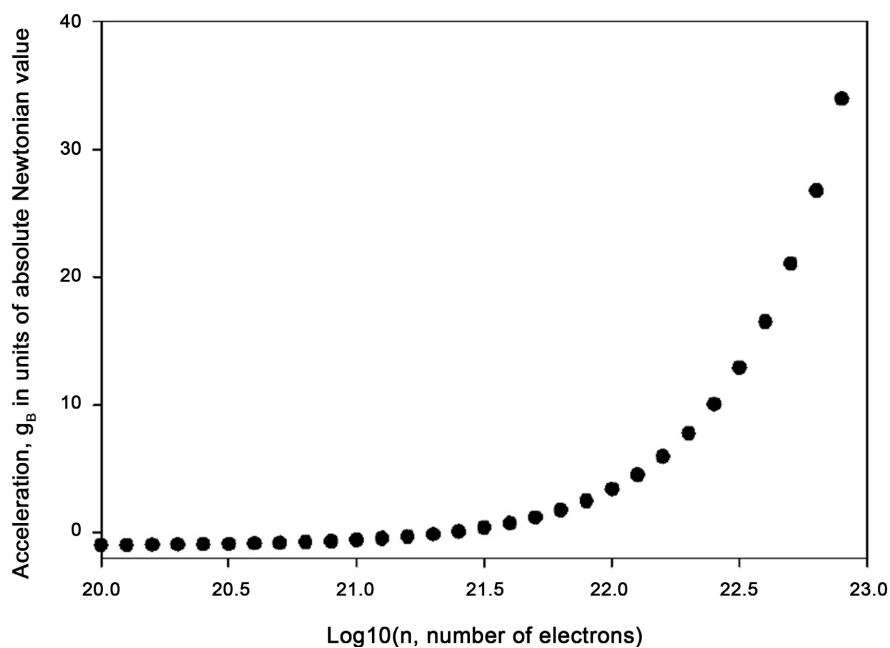


Figure 1. Acceleration vs. number of electrons.

2.2. Electrons with Uncharged Matter

In this section, we assume that ball lightning contains electrons, chiefly from the lightning strike that created it, and also uncharged matter. The uncharged matter

could be from the atmosphere and/or from soil as [38]-[45] maintain.

We now investigate the relationship between the number of electrons and the total mass of uncharged matter contained in ball lightning. These two quantities must satisfy Equation (5) because observations show that ball lightning does not fall. m is the total mass of ball lightning, so it must include the mass of uncharged matter, μ , as well as the mass of n electrons. Equation (5) becomes:

$$\frac{n^2}{\mu + n} = n_0 \tag{7}$$

n in the numerator is the number of electrons, and n in the denominator like μ is in units of electron mass.

To obtain the number of electrons as a function of the mass of the uncharged component, μ , we must solve the above equation for n . We choose to express μ in grams so we must divide it by $m_e = 9.1 \times 10^{-28}$, the mass of the electron.

$$n = \frac{n_0 + \sqrt{n_0^2 + \frac{4n_0\mu}{m_e}}}{2} \tag{8}$$

Figure 2 shows the relationship between n and μ . Both quantities are expressed as the logarithm to the base 10. In grams the range of μ in the figure is: 10^{-9} to 10^2 . For a given mass, n is the number of electrons ball lightning must have in order for it not to fall or rise, as observations show. If the actual number of electrons is greater than n , then the ball lightning will rise, if less than n , it will fall.

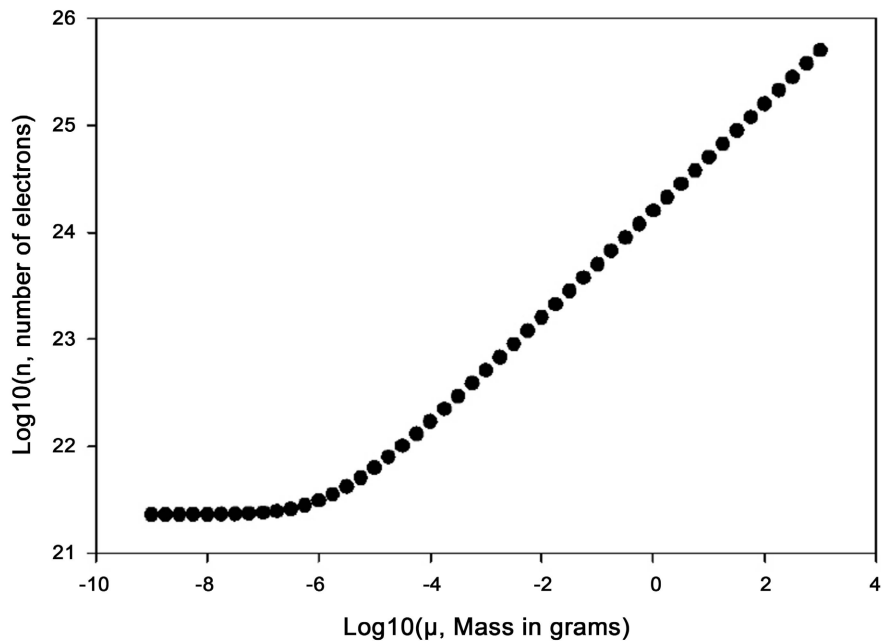


Figure 2. Number of electrons vs. mass.

3. Discussion

Equation (8) leads to the conclusion that the minimum number of electrons re-

quired to achieve the equality of downward Newtonian gravitational force and upward gravitational force of the electrostatic field energy is $n_0 = 2.3 \times 10^{21}$. n_0 is the value of n , when $\mu = 0$. That is it corresponds to a pure electron body. But, out of all the models proposed so far that suggest ball lightning is charged, the model with the highest estimate of the value of the charge is [18] with 0.1 C that is 6.24×10^{17} electrons. n_0 is orders of magnitude larger than this value, which suggests that none of these models is correct in their current form.

Does n_0 fit estimates of the energy in ball lightning? A lightning bolt containing n_0 electrons has an estimated energy of 3.68×10^{10} joules. This energy fits well with the estimated energy density, 10^{10} J/m³ of ball lightning [46].

How frequent are lightning strikes with $n \geq n_0$? [47] estimate that 0.1% of lightning strikes transport a charge > 350 C. n_0 corresponds to 368.5 C so they are roughly 0.1% of the total number of lightning strikes. They are therefore rare, about 1 in 1000 strikes. Nevertheless the total number of such strikes is appreciable. There are worldwide about 100 lightning strikes/s that is 3.15 billion/year. So every 10 s or about 3×10^6 per year is an estimate of the frequency of superbolts with $n \geq n_0$.

However, only a small fraction of these strikes, which may lead to ball lightning, are reported. This is because of geographical constraints: 1) Only a small fraction of the earth's surface at any instance is visible to humans. 2) reporting is more likely to take place in developed countries. [4] cites 5 - 15 reliable reports of ball lightning events per year. Considering these constraints we suggest this number is explained by the frequency of superbolts with $n \geq n_0$.

Experiments have been performed to create ball lightning. [38] simulated a lightning strike in the lab by applying a 10 - 20 kV direct current (DC) discharge to a 3-mm layer of soil, transferring up to 3.4 coulombs of charge. [48] reproduced ball-lightning-like "plasma fireballs" using a combination of air-gap electrical discharge and microwave radiation. [49]-[51] produced glowing plasma formations generated by discharges with polymer and metal materials. [52] created microwave-sustained plasma fireballs under atmospheric conditions, which exhibited some features of natural ball lightning. None of these experiments created ball lightning. However, they all possessed some features of ball lightning.

4. Conclusions

Observations show that ball lightning does not fall. It therefore appears to defy gravity. We invoke Einstein's theory of gravitation instead of Newton's theory of gravitation to explain these observations. Our theory rests on the circumstance of Einstein's theory that the electrostatic field energy associated with charged particles (in our case electrons) gravitates repulsively.

We suggest electrons chiefly from the lightning strike that caused the formation of the ball lightning remain in the ball lightning. If the number of electrons is greater than 2.3×10^{21} then it is possible for the upward gravitational acceleration of the electrons to equal the downward gravitational force of Newtonian gravita-

tional theory. The exact number of electrons required to achieve this equality depends upon the mass of uncharged matter in the ball lightning as **Figure 2** shows.

In addition to explaining why ball lightning does not fall, our theory also explains why the reporting of ball lightning sightings is so rare. This circumstance is due to the rarity of superbolts coupled with geographical and reporting constraints. We have therefore explained two major aspects of the phenomenon of ball lightning.

We conclude that ball lightning does not defy gravity. It indeed obeys the laws of gravitation, however, not Newton's law of gravitation rather Einstein's theory of gravitation.

Acknowledgements

Many thanks to Dr. and Mrs. William McCormick, whose generous support has provided the prerequisite financial basis and most importantly the necessary time to complete this project.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- [1] Boerner, H. (1999) Ball Lightning.
- [2] Barry, J.D. (2010) Ball Lightning and Bead Lightning.
- [3] Singer, S. (1971) The Nature of Ball Lightning.
- [4] Stenhoff, M. (1999) Ball Lightning, an Unsolved Problem in Atmospheric Physics.
- [5] Stephan, K.D. (2024) Could Ball Lightning Be Magnetic Monopoles?
- [6] Ralston, J.P. (2024) Is Ball Lightning a Signal of Magnetic Monopoles?
- [7] Rabinowitz, M. (2001) N-Dimensional Gravity: Little Black Holes, Dark Matter, and Ball Lightning. *International Journal of Theoretical Physics*, **40**, 875-901. <https://doi.org/10.1023/a:1004152729335>
- [8] Rabinowitz, M. (2001) Ball Lightning: Manifestation of Cosmic Little Black Holes. *Astrophysics and Space Science*, **277**, 409-426. <https://doi.org/10.1023/a:1012520609646>
- [9] Vuy, L.L. (2011) Artificial Ball Lightning Production and Exploitation Device for Zero Point Electric Energy Usage.
- [10] Zhitnitsky, A. (2025) Ball Lightning as a Profound Manifestation of Dark Matter Physics. *Universe*, **11**, Article No. 284. <https://doi.org/10.3390/universe11090284>
- [11] Altschuler, M.D., House, L.L. and Hildner, E. (1970) Is Ball Lightning a Nuclear Phenomenon? *Nature*, **228**, 545-547. <https://doi.org/10.1038/228545a0>
- [12] Ashby, D.E.T.F. and Whitehead, C. (1971) Is Ball Lightning Caused by Antimatter Meteorites? *Nature*, **230**, 180-182. <https://doi.org/10.1038/230180a0>
- [13] Muldrew, D.B. (2010) Solid Charged-Core Model of Ball Lightning. *Annales Geophysicae*, **28**, 223-232. <https://doi.org/10.5194/angeo-28-223-2010>
- [14] Lowke, J.J. (1996) A Theory of Ball Lightning as an Electric Discharge. *Journal of Physics D: Applied Physics*, **29**, 1237-1244.

- <https://doi.org/10.1088/0022-3727/29/5/018>
- [15] Tonks, L. (1960) Electromagnetic Standing Waves and Ball Lightning. *Nature*, **187**, 1013-1014. <https://doi.org/10.1038/1871013a0>
- [16] Tsui, K.H. (2003) Ball Lightning as a Magnetostatic Spherical Force-Free Field Plasmod. *Physics of Plasmas*, **10**, 4112-4117. <https://doi.org/10.1063/1.1605949>
- [17] Tsui, K.H. (2001) Force-Free Field Model of Ball Lightning. *Physics of Plasmas*, **8**, 687-689. <https://doi.org/10.1063/1.1343511>
- [18] Nikitin, A.I., Nikitin, V.A., Velichko, A.M. and Nikitina, T.F. (2023) Explosions of Ball Lightning Inside Enclosed Spaces. *Atmosphere*, **15**, Article No. 2. <https://doi.org/10.3390/atmos15010002>
- [19] Stephan, K.D. (2016) Extension of Relativistic-Microwave Theory of Ball Lightning Including Long-Term Losses and Stability.
- [20] Wu, H.-C. (2016) Relativistic-Microwave Theory of Ball Lightning. *Scientific Reports*, **6**, Article No. 28263. <https://doi.org/10.1038/srep28263>
- [21] Wessel-Berg, T. (2003) A Proposed Theory of the Phenomenon of Ball Lightning. *Physica D: Nonlinear Phenomena*, **182**, 223-253. [https://doi.org/10.1016/s0167-2789\(03\)00126-x](https://doi.org/10.1016/s0167-2789(03)00126-x)
- [22] Handel, P. (2008) Theory of the Motion of Ball Lightning. *APS Meeting Abstracts*, St. Louis, 11-15 April 2008, K1.018.
- [23] Einstein, A. (1915) Zur allgemeinen Relativitätstheorie. *Sitzungsberichte der Königlich Preussischen Akademie der Wissenschaften*, 778-786.
- [24] McGruder, C.H. (1978) Field Energies and Principles of Equivalence. *Nature*, **272**, 806-807. <https://doi.org/10.1038/272806a0>
- [25] Muldrew, D.B. (1990) The Physical Nature of Ball Lightning. *Geophysical Research Letters*, **17**, 2277-2280. <https://doi.org/10.1029/gl017i012p02277>
- [26] Tennakone, K. (2011) A Model of Ball Lightning as a Formation of Water Molecules Confining an Electric Charge and the Classical Theory of the Electron. *International Journal of Theoretical Physics*, **51**, 1013-1021. <https://doi.org/10.1007/s10773-011-0975-8>
- [27] Shelton, J.D. (2011) Eddy Current Model of Ball Lightning.
- [28] Peer, J. and Kendl, A. (2010) Transcranial Stimulability of Phosphenes by Long Lightning Electromagnetic Pulses. *Physics Letters A*, **374**, 2932-2935. <https://doi.org/10.1016/j.physleta.2010.05.023>
- [29] Cooray, G. and Cooray, V. (2008) Could Some Ball Lightning Observations Be Optical Hallucinations Caused by Epileptic Seizures? *The Open Atmospheric Science Journal*, **2**, 101-105. <https://doi.org/10.2174/1874282300802010101>
- [30] McGruder, C.H. (2025) Galileo vs. Aristotle, Principles of Equivalence and the Gravitational Acceleration of Atoms According to General Relativity. *Journal of Modern Physics*, **16**, 1026-1036. <https://doi.org/10.4236/jmp.2025.167053>
- [31] Boerner, H. (2023) The Role of Free Electrons in Ball Lightning Creation.
- [32] Fedosin, V.I. and Kim, A.S. (1984) Electron-Ionic Model of Ball Lightning. *Journal of New Energy*, **6**, 11-18.
- [33] Dvornikov, M. (2010) Formation of Bound States of Electrons in Spherically Symmetric Oscillations of Plasma. *Physica Scripta*, **81**, Article ID: 055502. <https://doi.org/10.1088/0031-8949/81/05/055502>
- [34] Dvornikov, M. (2011) Axially and Spherically Symmetric Solitons in Warm Plasma. *Journal of Plasma Physics*, **77**, 749-764. <https://doi.org/10.1017/s002237781100016x>

- [35] Dvornikov, M. (2011) Effective Attraction between Oscillating Electrons in a Plasmod via Acoustic Wave Exchange. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **468**, 415-428. <https://doi.org/10.1098/rspa.2011.0276>
- [36] Neugebauer, T. (1977) Quantum Mechanical Theory of Ball Lightning. *Acta Physica Academiae Scientiarum Hungaricae*, **42**, 29-47. <https://doi.org/10.1007/bf03157197>
- [37] Fedosin, S.G. (2024) Electron-Ion Model of Ball and Bead Lightning. *Journal of Atmospheric and Solar- Terrestrial Physics*, **265**, Article ID: 106374. <https://doi.org/10.1016/j.jastp.2024.106374>
- [38] Abrahamson, J. and Dinniss, J. (2000) Ball Lightning Caused by Oxidation of Nanoparticle Networks from Normal Lightning Strikes on Soil. *Nature*, **403**, 519-521. <https://doi.org/10.1038/35000525>
- [39] Cen, J.Y., Yuan, P. and Xue, S. (2014) Observation of the Optical and Spectral Characteristics of Ball Lightning. *Physical Review Letters*, **112**, Article ID: 035001. <https://doi.org/10.1103/physrevlett.112.035001>
- [40] Paiva, G.S., Pavão, A.C., Alpes de Vasconcelos, E., Mendes, O. and Felisberto da Silva, E. (2007) Production of Ball-Lightning-Like Luminous Balls by Electrical Discharges in Silicon. *Physical Review Letters*, **98**, Article ID: 048501. <https://doi.org/10.1103/physrevlett.98.048501>
- [41] Stephan, K.D. and Massey, N. (2008) Burning Molten Metallic Spheres: One Class of Ball Lightning? *Journal of Atmospheric and Solar- Terrestrial Physics*, **70**, 1589-1596. <https://doi.org/10.1016/j.jastp.2008.05.014>
- [42] Aleksandrov, V.Ya., Borodin, I.P., Kechenko, E.V. and Podmoshenskii, I.V. (1982) Rapid Coagulation of Submicron Aerosols into Filamentary Three-Dimensional Structures. *Soviet Physics: Technical Physics*, **27**, 527-529.
- [43] Dmitriev, Bakhtin, B.I. and Martynov, V.I. (1981) Thermal Effects of Ball Lightning. *Soviet Physics: Technical Physics*, **26**, 1518-1520.
- [44] Abrahamson, J. (2001) Ball Lightning from Atmospheric Discharges via Metal Nanosphere Oxidation: From Soils, Wood or Metals. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, **360**, 61-88. <https://doi.org/10.1098/rsta.2001.0919>
- [45] Dikhtyar, V. and Jerby, E. (2006) Fireball Ejection from a Molten Hot Spot to Air by Localized Microwaves. *Physical Review Letters*, **96**, Article ID: 045002. <https://doi.org/10.1103/physrevlett.96.045002>
- [46] Goodlet, B.L. (1937) Lightning. *Journal of the Institution of Electrical Engineers*, **81**, 1-26. <https://doi.org/10.1049/jiee-1.1937.0104>
- [47] Nag, A., Mallick, S., Rakov, V.A., Howard, J.S., Biagi, C.J., Hill, J.D., *et al.* (2011) Evaluation of U.S. National Lightning Detection Network Performance Characteristics Using Rocket-Triggered Lightning Data Acquired in 2004-2009. *Journal of Geophysical Research (Atmospheres)*, **116**, D02123. <https://doi.org/10.1029/2010jd014929>
- [48] Ofurton, H., Kondo, N., Kamogawa, M., Aoki, M. and Ohtsuki, Y. (2001) Experimental Conditions for Ball Lightning Creation by Using Air Gap Discharge Embedded in a Microwave Field. *Journal of Geophysical Research: Atmospheres*, **106**, 12367-12369. <https://doi.org/10.1029/2000jd900726>
- [49] Egorov, A.I., Stepanov, S.I. and Shabanov, G.D. (2004) Laboratory Demonstration of Ball Lightning. *Physics- Uspekhi*, **47**, 99-101. <https://doi.org/10.1070/pu2004v047n01abeh001691>
- [50] Emelin, S.E., Bychkov, V.L., Astafiev, A.M., Kovshik, A.P. and Pirozersky, A.L. (2012)

Plasma Combustion Nature of Artificial Ball Lightning. *IEEE Transactions on Plasma Science*, **40**, 3162-3165. <https://doi.org/10.1109/tps.2012.2217351>

- [51] Bychkov, V.L., Chernikov, V.A., Osokin, A.S., Stepanov, A.I. and Stepanov, I.G. (2015) Modeling of Artificial Ball Lightning with a Help of Capillary Discharge. *IEEE Transactions on Plasma Science*, **43**, 4043-4047. <https://doi.org/10.1109/tps.2015.2478441>
- [52] Stephan, K.D. (2006) Microwave Generation of Stable Atmospheric-Pressure Fireballs in Air. *Physical Review E*, **74**, Article ID: 055401. <https://doi.org/10.1103/physreve.74.055401>