On the Nature of Ball Lightning

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The author proposes a model of ball lightning based on a mechanistic interpretation of John Wheeler's ideas. It is assumed that ball lightning is a quasi-particle that has the Planck mass and consists of closed contours, which in turn are based on the magnetic and gravity force balance. These contours are hard packed in a small volume of ball lightning, forming a multilayer capacitor containing a substantial charge and electrostatic energy. This paper provides calculations of characteristic parameters of ball lightning, which are well consistent with its phenomenology.

1　Introduction

There are many theories about ball lightning. However, the nature of this mysterious phenomenon remains unclear. This paper proposes a model of ball lightning based on a mechanistic interpretation of John Wheeler's concept. Previously, such an approach has been successfully applied to construct both micro-world and space models [1, 2, 3, etc.].

To some extent, the model proposed is similar to the quantum model by Geert Dijkhuis, Professor at Eindhoven University of Technology and Secretary of the International Committee on Ball Lightning. His model suggests that ball lightning is a macroscopic quantum object. Earlier, a similar hypothesis was proposed by Boris Ignatov [4]. Nevertheless, it must be noted that there is no complete understanding of the nature of such objects. It is assumed that a quasiparticle cannot carry a substance. It only carries energy, pulse, and momentum, while the electrons inside such an object are completely coherent and make up a single wave function. Energy of such a quasiparticle is gradually dissipating, in the visible range in particular. Therefore, ball lightning can be observed as an optical object.

2　Presuppositions

Recall that (according to Wheeler) there are original primary elements of space and matter, which have different names - *wormholes*, *appendices*, *current tubes*, *threads* or *force lines* of a field. If they are real objects and not just mathematical abstractions, in physical terms, they must be some kind of vortex structures resting on the phase boundary (surface). In particular, Wheeler treats charges as singular points on the surface source-drain connected by current tubes in an additional dimension forming a closed *contour*.

Paper [1] shows that, from a purely mechanistic point of view, the *charge* is proportional to its momentum about the contour of the vortical tube and reflects the extent of non-equilibrium of physical vacuum; *spin* is proportional to the angular momentum relative to the longitudinal axis of the contour, respectively; and the *magnetic interaction* between the conductors is similar to forces existing between the current tubes. It is customary that a single element of such a tube is an element with the size of a classical electron radius r_e and its mass m_e.

The model of ball lightning was only built using the ratio of fundamental interactions as in the above-mentioned papers of the author. The mechanistic interpretation of Wheeler's ideas makes it possible to record formulae for electric and magnetic forces in a *Coulomb-free* form, where the charge is replaced with the ultimate electron momentum. In this case, the electric and magnetic constants, ε_0 and μ_0, are as follows:

$$\varepsilon_0 = m_e / r_e = 3.33 \times 10^{-16} \text{ kg/m},\tag{1}$$

$$\mu_0 = 1/(\varepsilon_0 c^2) = 0.0344 \text{ N}^{-1},\tag{2}$$

Where the electric constant becomes linear density of the vortical tube and the reciprocal of the magnetic constant is the centrifugal force produced by rotation of the vortical tube element with m_e mass with the velocity of light c along r_e radius. This value is also equivalent to the force existing between two elementary charges at the given radius.

For the purpose of mutual comparison of interactions, formulae for the electric, magnetic, gravity, and inertial forces are written in a dimensionless form with a single dimension factor of force $1/\mu_0$. With (1) and (2) in mind, we have the following:

$$F_e = (1/\mu_0)(r_e / r_0)^2 z_{e1} z_{e2},\tag{3}$$

$$F_m = (1/\mu_0)(l / 2\pi r_0)(r_e /(c \times [c]))^2 z_{e1} z_{e2},\tag{4}$$

$$F_g = (1/\mu_0)(1/f)(r_e / r_0)^2 z_{g1} z_{g2},\tag{5}$$

$$F_i = (1/\mu_0)(r_e / r_0)(V_0 / c)^2 z_g,\tag{6}$$

Where V_0, r_0, l, z_e, z_g, and f stand for circumferential velocity, circumferential radius or distance between vortical tubes, length of the vortex tube (thread) or contour, relative values of the charge and mass of the electron charge and mass, and the electric-gravity force ratio, respectively, with the latter having the following formula with the same designations:

$$f = c^2/(\varepsilon_0 \gamma) = 4.16 \times 10^{42}\tag{7}$$

Where γ is the gravitational constant.

3   Calculation of Characteristic Parameters of Ball Lightning

Ball lightning often originates from streak one. Imagine streak lightning as a bundle of vortex threads, which (under certain conditions) form vortical current tubes. The latter, in turn, are closed into contours. It is obvious that there must be balances of some pairs of interactions for ball lightning to exist. They are the following:

1. Ball lightning mass M satisfies the condition of equality of *electric and gravity forces*, so with unit charges we have the following:

$$M = f^{1/2} m_e = 1.86 \times 10^{-9} \text{ kg},\tag{8}$$

Which is in agreement with the Plank mass by order of magnitude.

2. Closed contour branches with opposed currents satisfy the balance of *magnetic and gravity forces* resulting in a linear geometric mean dimension of the contour:

$$l_k = (r_0 l)^{1/2} = (z_{g1} z_{g2} / z_{e1} z_{e2})^{1/2} (2\pi / f)^{1/2} c \times [\text{sec}],\tag{9}$$

Where the ratio of the product $\varepsilon = (z_{g1} z_{g2})/(z_{e1} z_{e2})$ is an *evolutionary parameter* that characterizes the state of the environment and its changes as the mass carriers dominate over electric ones, and in fact shows the distinction between material medium and vacuum. Hereinafter, we shall take it

as being close to the unit in our case, while $l_k = 3.68 \times 10^{-13}$ m, and the vortical tube's mass is

$$m_k = \varepsilon_0 l_k = 1.19 \times 10^{-28} \text{ kg}. \tag{10}$$

In addition, if we express vortical tubes' masses in (9) − $z_g m_e$ as $\varepsilon_0 l$, then we shall get the following relation between the contour axes for unit charges with (7) in mind:

$$r_0 / l = (2\pi \rho_e \gamma \times [c^2]) = 17070 \approx a^2, \tag{11}$$

Where ρ_e is the electron density equal to $m_e / r_e^3 = 4.071 \times 10^{13}$ kg/m^3; and a is the reverse fine structure constant equal to 137.036. Thus, the individual contour is most likely to have axes equal to the size of an electron r_e and Bohr atom $r_e a^2$.

3. Vortical tubes of a contour consist of a number of unidirectional parallel individual vortex threads spinning about the longitudinal axis of the contour with circumferential velocity V_{0i}. Their stability is ensured by the balance of *magnetic and inertial forces*, which give rise to the following formula:

$$V_{0i} = (z_{e1} z_{e2} / z_g)^{1/2} (r_e l / 2\pi)^{1/2} / [\sec]. \tag{12}$$

Individual vortex filaments having length l and mass carriers in the number of $z_g = l / r_e$ are spinning about the longitudinal axis along an indefinite radius. In the case of unit charges, we have the following minimum circumferential velocity about the longitudinal axis:

$$V_{0i} = r_e / ((2\pi)^{1/2} \times [c]) = 1.124 \times 10^{-15} \text{ m/sec}. \tag{13}$$

The total number of contours (and the same of unit charges, respectively) may be as follows:

$$z = M / m_k = 1.56 \times 10^{19}. \tag{14}$$

The way these contours are packed in the volume of ball lightning is unclear. Possibly, a contour may be one-dimensional with the total length of $z \times l_k$. It can be expected that with transformation into the more energetically favourable structure the contour (folding repeatedly) forms a large number of loops or cells, which are enclosed in a spherical volume with a bright centre (nucleus). In both cases, with the elements being the most densely packed in the volume, the reduced minimum linear dimension of the outer spherical surface will be as follows:

$$l_{min} = z^{1/2} l_k = 0.00145 \text{ m}, \tag{15}$$

However, if we consider the ratio in (11) and take one of the axes of the Bohr radius instead of l_k for individual contours, then we can estimate the maximum size of such a sphere as $l_{max} \approx 0.00145 \times a \approx 0.2$ m.
Let us calculate the rest limit parameters of ball lightning − energy, charge, electric potential of streak lightning required for generation of ball lightning, and its ultimate density:

$$E_{lim} = M c^2 = 1.67 \times 10^8 \text{ J}, \tag{16}$$

$$q_{lim} = z e_0 = 2.50 \text{ K}, \tag{17}$$

$$U_{lim} = E_{lim} / q_{lim} = 6.68 \times 10^7 \text{ V}. \tag{18}$$

The density will be calculated taking l_{min} as the sphere's diameter:

$$\rho_{lim} = M / ((4/3)\pi \; (l_{min}/2)^3) = 1.17 \; \text{kg/m}^3, \tag{19}$$

Which corresponds to the air density.

Contour branches with parallel unidirectional currents have to twist, so ball lightning contours are gradually opening losing the charge. Therefore, ball lightning has a sort of an electrostatic tail behind. The maximum lifetime of ball lightning can be determined in a similar way as the neutron lifetime [2], i.e., as the *time constant* of the contour deformation (the ratio of the contour's characteristic dimension to the circumferential velocity):

$$\tau_{lim} = \; l_k / V_{0i} = 327 \; \text{sec.} \tag{20}$$

When crossing the initial surface of our world, an open contour (vortical tube) actually forms an elementary charge (according to Wheeler). It can be assumed that the physical basis of ball lightning is formed by electrons. Their fermionic part is arranged into corresponding structures observable in the form of a fireball, while their bosonic parts converge in the centre of the ball going to the additional dimension (Y area) [2].

Let us also determine the capacity, electrostatic energy, and size required for ball lightning with q_{lim} charge. Paper [5] found a connection between new electrical units in a *Coulomb-free* form and SI-system units. It was shown that the mass of electrons 2.90×10^{-6} kg on the capacitor plates corresponded to one Farad. Velocity of 587 m/sec corresponded to one Volt, with the electrostatic capacity of the surface at which the charge begins to flow spontaneously into the external environment being $U_m = 511,000$ V.

Thus, ball lightning has the following capacity:

$$C = z \, m_e / 2.90\times10^{-6} = 4.89\times10^{-6} \, \text{F}, \tag{21}$$

With the same result in the SI system:

$$C = q_{lim} / 511000 = 4.89\times10^{-6} \; \text{F}, \tag{22}$$

And the maximum electrostatic energy of ball lightning being

$$E_m = C U_m^2 / 2 = 6.39\times10^5 \; \text{J} \, . \tag{23}$$

To have such a capacity, ball lightning must have a multilayer structure, e.g., the structure of a multilayer spherical capacitor. Paper [5] shows that the average distance between unit charges of a charged sphere with R radius is $\pi(Rr_e)^{1/2}$. Let us assume that the average linear dimension between the charges in the volume of ball lightning is the same. Then we can determine the size of ball lightning through the following equation:

$$((4/3)\pi R^3/z)^{1/3} = \pi(Rr_e)^{1/2}, \tag{24}$$

Therefore

$$R = (3\pi^2 z \, /4)^{2/3} r_e = 0.067 \; \text{m.} \tag{25}$$

Let us determine the temperatures of the nucleus and the outer shell with the assumption that the radiation of ball lightning is the radiation of a blackbody. If the total energy is evenly lost over the lifetime of ball lightning, the average radiation power shall be as follows:

$$N = E_m / \tau_{lim} = 1950 \text{ W}, \tag{26}$$

Then

$$T = (N/\sigma S)^{1/4}, \tag{27}$$

Where σ is a Stefan-Boltzmann constant equal to 5.67×10^{-8} $Wm^{-2}(^0K)^{-4}$; and S is the area of the spherical surface of ball lightning. Taking l_{min} as the nucleus diameter and l_{max} as the diameter of the outer shell, we calculate the respective areas S and determine their temperatures using formula (27) – $8,500^0$K and 724^0K.

External appearance of ball lightning, its behaviour, and results of its effect on the environment are extremely varied. Given its unpredictability, it is rarely possible to obtain objective instrumental data on ball lightning.

In his paper [6], Mikhail Dmitriev – a chemist having vast experience in working with low-temperature plasma – describes an encounter with ball lightning and an attempt to make a chemical analysis of ionized air behind it. Based on the analysis results, the author estimated the potential of ball lightning discharge at 300-400 kV. The temperature, degree of ionization, and concentration of charged particles in ball lightning was estimated at 1.14×10^{17} per cm^3 judging on its glow. It is easy to calculate that, in accordance with the proposed model and given such a concentration, the estimated diameter of ball lightning with z unit charges shall be 6.4 cm, which corresponds to its typical size. This means that the discharge potential and charge concentration of real ball lightning encountered by Dmitriev are consistent with the estimated model.

Since ball lightning does not consist of atoms and molecules, it does not interact with molecules of other media. This explains its ability to penetrate through obstacles and move against the wind, but actively respond to electric and magnetic fields at the same time.

Finally, it should be noted that people often associate ball lightning with a living being. Let us assume that life can be organized on another material basis. Then, indeed, given the number of unit elements ($z = 1.56 \times 10^{19}$) and complexity of their packing in the volume of ball lightning, it is appropriate to draw an analogy with a DNA strand, which is two meters long, packed in a microscopic cell nucleus, and contains information about the structure and behaviour of a living organism.

Conclusion

Thus, model ball lightning is a ball with its size ranging from 0.14 to 20 cm (its typical diameter is 13.4 cm), having density of no more than 1.17 kg per m^3, glow temperature of 724 to $8,500^0$K, and energy of 639 kJ concentrated in a small volume in the form of an electrostatic charge with 511 kV potential. During the lifetime of ball lightning (up to 6.5 minutes), it is constantly losing the charge leaving an ionised trail behind. Ball lightning is able to penetrate obstacles.

In general, eyewitness accounts are in good agreement with the calculated characteristic parameters of the model object. Of course, some phenomena of real ball lightning fall outside the scope of the obtained characteristic parameters. At least this is due to the fact that its charge can be formed by not only electrons, but also by ions, and the evolutionary parameter ε may exceed the unit.

The ball lightning phenomenon and its complete internal organization can only be understood on the basis of an appropriate theory. However, from a phenomenological point of view, this model of ball lightning is in good agreement with the real object by its appearance and its basic aspects, and can serve as the basis for such a theory.

References:

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