The physical theory of ball lightning

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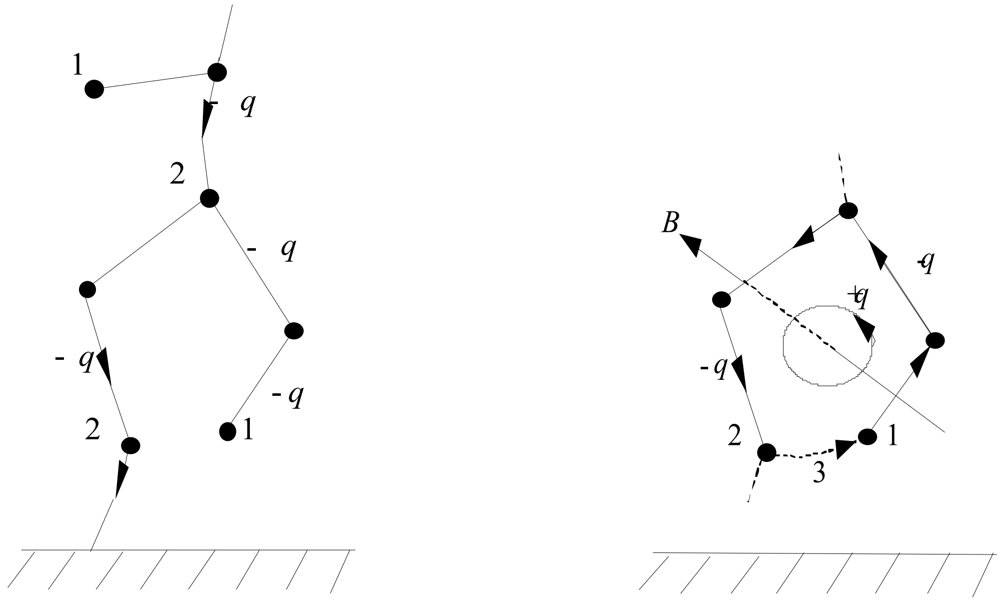
The analysis of modern models of ball lightning displays, that they are unsatisfactory on a series of tests. The model of ball lightning is offered, which exterior electronic envelope is retained by interior volumetric positive charge. The compounded electron motion in an outer envelope creates the strong magnetic field driving a state of ionized hot air inside ball lightning.

Any model of ball lightning (BL) must explain a stable form of BL at a motion into the wind and at passage through glasses, its life time, electrical effects of BL, give explanation of a radio-frequency radiation, sparking and odor from BL and its possible explosion.

Within the framework of electron-ionic model natural BL can be an immediate corollary of a linear lightning, when the thunderstorm cloud is discharged on ground, transmitting it negative electricity (or at the discharge of adjacent clouds). In a fig. 1a the secondary branches and main channel of a lightning charged accordingly with sluggish and promptly migrated electrons are exhibited. A prompt electron motion and basic flash of a lightning start after linking a main channel with ground; thus luminous part of a lightning grows from ground to a cloud. The electrons, which are taking place in secondary branches, also move to a main channel and are poured through it on ground. Thus the almost closed circuit of an electronic current is possible (fig.1b), when at its centre there is a magnetic field with an induction B. In electrified air around of a lightning there are many positively ionized atoms, which one start to be torqued around of lines of a magnetic field and by that are arrested at centre. In turn current of electrons from the channel 2 can skip on a branch 1 through area 3, supporting the further close current. An indispensable requirement for this purpose should be the force retaining electrons on a closed orbit.



a) b)

Fig. 1. a) 1 – secondary branches of lightning, 2 – primary channel, in which the electrons are moving (are marked $-q$).
b) The electron motion from a secondary branch 1 in a primary channel 2 of lightnings can be made through area 3. B – induction of a magnetic field from an electron current. The ions with a charge $+q$ are spun around lines of the magnetic field

At sufficient quantity of positively ionized atoms at centre they can attract to itself electrons and by that to provide their inconvertible gyration. Outgoing from an offered picture, in a fig. 2 the equatorial section of BL model by the way of rotationally symmetric configuration with a spherical electronic current is presented. The positively ionized atoms are at atmospheric pressure in very hot air inside BL after shock of a linear lightning. Promptly migrated electrons in an outer envelope generate a magnetic field with an induction B, which one retains positively ionized atoms on orbits inside BL. At last, the electrical attraction of positively ionized atoms and electrons with negative charge retains electrons in an outer envelope from dispersion, being by a main body of a centripetal force. In view the spherical shape of BL the radius of gyration r of exterior electron atmosphere around of a general axis diminishes in accordance with transition from equator to poles. This specified rather inconvertible configuration allows explaining an apparent lifetime BL, which essentially exceed lifetime of homogeneous ion-impact plasma at atmospheric pressure. The electronic envelope efficiently isolates of high-temperature air inside BL, retarding transport of energy to a surrounding medium. The positively ionized atoms inside

BL practically are not attracted by electrons from an outer envelope, as the electric field from electrons inside an orb is equal to null because of an equilibration of all electrical forces. Therefore ions can be proportioned uniformly on all BL volume, and the recombination of ions and electrons is essentially retarded.

As it is visible from a fig. 1б, BL as a matter of fact there is a small part of a linear lightning, twisted in a skein with the typical size 10 – 40 cm. Accordingly in both types of lightnings currents and the magnetic field can be close on quantity.

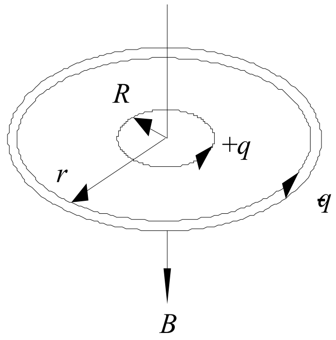


Fig. 2. Equatorial section of model of ball lightning select ring on electronic envelop of the spheroidal shape. R – radius of gyration of ions around of a magnetic field with an induction B , r – radius of exterior electronic envelop

The typical parameters of a linear lightning are those: section of a main channel about 10^{-2} m^2; currents in the main discharge from 10^4 A and up to $5 \cdot 10^5$ A; during the short discharge about 10^{-3} s may be transferred 20 coulombs of an electricity; temperature of air in the channel of a lightning reaches 25000 K; an electron concentration in the channel of a linear lightning up to $4 \cdot 10^{18}$ in 1 cm^3; velocities of heat motion for ions not less than 10^4 m/s, for electrons more than 10^6 m/s. The probability of BL observation is insignificant and on a statistician one BL is noted against 1000 usual lightnings.

Let's designate through M, V, R and m, v, r masses, travelling speeds and radiuses of gyration of ions and electrons accordingly; $\boldsymbol{B}$ – induction of a magnetic field; N_i – quantity of uncompensated positively ionized atoms inside BL ; N_e – quantity of mobile electrons in an outer envelope of BL ; q – unit electrostatic charge; i – current of electrons on an orbit of radius r; $\varepsilon, \varepsilon_0$ – relative complex dielectric constant and permittivity of vacuum; μ, μ_0 – relative magnetic conductivity of medium and permeability of vacuum. For simplification of calculations we shall to consider, that the charges and currents in basic are massed near to an equatorial plane or are disposed like the cylinder, and ions are singly.

The equilibrium condition for electrons moving in an outer envelope, relates axipetal and electrical forces:

$$\frac{mv^2}{r}=\frac{N_i q^2}{4\pi\varepsilon\varepsilon_0 r^2}-\frac{N_e q^2}{4\pi\varepsilon\varepsilon_0 r^2}. \qquad (1)$$

The first expression in a right member (1) features an attractive force between an electron and volumetric interior ionic charge, second – repulsive force of electrons in an outer shell from each other. The balance of forces (1) will run in the case, when the total number of uncompensated positive charges N_i will be insignificant to exceed number of mobile electrons in an outer envelope N_e. Therefore, BL as a whole should be charged positively, having a charge $Q=q(N_i-N_e)$. On the other hand, the total charge of BL can not exceed such quantity, at which intensity of an electric field on surface of BL exceed $E_0=30$ kV/cm in order to prevent a disruption of ambient air. From here we calculate a maximal charge of BL :

$$Q_0=4\pi\varepsilon\varepsilon_0 E_0 r^2. \qquad (2)$$

The availability of a major electric intensity near BL and vigorous electrons confirms by numerous observations of their fizz, scratching noise and emission of sparks as at electric discharge. Besides, the samples of air taken after passage BL, have shown the heightened content of ozone and nitric oxides (approximately in 50 – 100 times above than norm). It is known, that the demanded relation of concentrations of ozone and nitric oxides can be received at electric discharge in air with intensity of electric field up to 4 kV/cm, and the estimate of indispensable electrical energy in such equivalent discharge for full lifetime of BL gives value 530 J.

Expressing a charge Q from (1) and equating to (2), we gain:

$$\frac{v^2}{r}=\frac{qE_0}{m}. \qquad (3)$$

In a right member (3) there are stationary values. Accepting, that the greatest possible velocity of electrons v is peer to speed of light with, we discover greatest BL radius with limiting quantity of electric charge:

$$r = 17\ \text{cm}, \qquad Q = Q_0 = 9.6 \cdot 10^{-6}\,\text{C}, \tag{4}$$

under condition of $v \cong c$.

Curious feature of BL is that the total energy is plus, and at the same time BL is relatively stable. Other contrast are the gravitation-bound bodies, the stability which one is accompanied negativity of their total energy. In both cases the total energy grows modulo at diminution of a volume of object at invariable quantity of particles. In BL as in plasma object the additional external pressure gives in amplification of currents and magnetic field (this is characteristic feature of plasma), and at diminution of a volume electrostatic energy is growing.

Due to the charge (4) BL can be slid under influence of electric fields. BL sometimes fall out of clouds and are promptly guided to ground, there are impacted and blast out. Frequently this motion happens along the channel just of arisen linear lightning. Close connection between places of occurrence of BL and shocks of linear lightnings directs at that, that in some cases BL is derived from one linear lightning and is erased by other linear lightning. BL, arisen in proximity of the ground, are usually slid slowly and can stop for some subjects, move into the wind or even to be lifted in clouds. These features of behavior can be quite explained by activity of strong electric fields between clouds and salience subjects on ground, periodically oscillating at the discharges of linear lightnings and a motion of clouds down to a veering of a field gradient. The potential difference between clouds and ground can reach quantity up to 10^8 V, that at a cloud height above ground in 1 km gives intensity of a field 10^5 V/m instead of those 100 V/m, which one are supervised at a clear weather. Besides, owing to a heat of air inside BL its medial density differs from density of an ambient air, so that to electrical forces it is necessary to add lifting force of the Archimedes. The balance of the indicated forces is carried out, apparently, for bound either attached BL, or soaring fixed, or bound with subjects. During life of BL its charge can vary because of interaction with encirclement or at partial decay, giving to change of equilibrium state. So, at transition from attached BL to free it is usual soar up and then on a slanting line leaves to clouds.

In table there are parameters of BL of different sizes. The radius of the small BL is near 1 cm, and kinetic energy of electrons approximately equal to magnetic energy. Almost all energy of BL with radius 7 cm (500 J) is consist of energy of plasma, including a kinetic energy of particles. The most power BL with radius 17 cm has aggregate energy by quantity 10.6 kJ, and only part of it (3.3 kJ) is electromagnetic energy.

Parameters of ball lightnings of different sizes

r, cm	i, A	B, T	W, J
1	20	$1{,}3 \cdot 10^{-3}$	2,2
7	$2{,}9 \cdot 10^{3}$	$2{,}6 \cdot 10^{-2}$	503
17	$1{,}4 \cdot 10^{5}$	0,5	10600

Electron-ionic model can explain not only the structure and parameters of BL, but also the structure of bead lightnings (The article *From ball lightning to model of bead lightnings* is in print now).

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