Simulation of the ball lightning temperature field

Aleksandr Kanareykin[1*]

[1]Sergo Ordzhonikidze Russian State University For Geological Prospecting, 117997, Miklouho-Maclay St. 23., Moscow, Russia

Abstract. The article is devoted to such a natural phenomenon as ball lightning. The relevance of the work is due to the fact that the phenomenon itself is widespread, but in itself has not been sufficiently studied. In it, the ball lightning is considered as a plasma ball. The main purpose of the work is mathematical modeling of the lightning temperature field taking into account radiation heat transfer. Based on the obtained result, an analysis of the behavior of the temperature field was carried out.

1 Introduction

Despite the fact that the physical nature of linear lightning was revealed more than two centuries ago, the nature of ball lightning still remains unsolved. Scientists are not completely sure whether this name corresponds to its physical essence, or whether it has a completely different nature.

Currently, a ball lightning is called any spherical object glowing and moving in the air, formed after a lightning strike or arising in the room as a result of the appearance with a hiss from an outlet or telephone.

In the vast majority of cases, this phenomenon occurs during the period of thunderstorm activity, when ordinary lightning is observed, and the intensity of the atmospheric electric field is especially high. However, there are separate reports of the appearance of ball lightning in clear weather. The causes of this phenomenon have not yet been established. It may have been observed near sources, converters (transformers) or high voltage power lines. Such "ball lightning" most often represent short-term flashes and differ significantly from thunderstorms, both in time and in other properties.

Hundreds of hypotheses have been put forward for the formation and structure of this object, but none of them can fully explain the amazing properties of ball lightning. All existing hypotheses are conditionally divided into two groups. One of them includes hypotheses about the continuous flow of energy to it from the outside, supporting its glow. According to another, ball lightning consists of a substance inside which processes occur, accompanied by the release of energy.

Scientists can't say anything concrete about the origin of ball lightning yet. There is an assumption that it occurs at the meeting point or intersection of the leaders of linear lightning. However, according to eyewitnesses, ball lightning can arise from the ground and water at the site of an ordinary lightning strike or pops out of telephones, electrical outlets, etc. In the last two examples, it can be assumed that the cause of lightning is not the

* Corresponding author: kanareykins@mail.ru

telephone itself or the outlet, but the wires connected to them, through which the "lightning", in the form of an electric discharge, it could move when it hit a pole located on the street. The formation of a ball lightning film is obviously based on gas emissions or blisters (bubbles) formed when heating the insulation of wires made of rubber, polyethylene or polyvinyl chloride at the places where they are connected to an outlet or telephone. The appearance of a hissing sound in this case is obviously the result of the conversion of the insulation of the wires. With an electric discharge at the point of contact, the formation of ozone is possible, which is directly involved in the formation of the film and ozonides.

It is noted that thunderstorms are more often observed over objects or places of land associated with the formation of a large number of dust and gas emissions into the atmosphere. At the same time, linear lightning strikes more often in places where aerosols and emissions from chemical and oil refineries accumulate.

There is no unanimous opinion that the movement of lightning depends on air currents, because some eyewitnesses claim that ball lightning can move against the wind. Most likely, it moves in the direction of the gradient of the distribution of negative charges in this part of the atmosphere. The tortuous trajectory of the ball lightning can be explained by the chaotic location of sites and objects with negative charges.

It is this property that can explain the desire and ability of ball lightning to penetrate into the room through cracks and holes, the size of which is much smaller than the size of the lightning itself. This is obviously explained by the attraction of positively charged atoms located inside it to negatively charged particles (electrons) emitted by switched-on electrical appliances that are in large numbers in the room.

The glow of the ball lightning is partially maintained due to the constant flow from outside into the bubble through a film of ionizing particles emitted by the Sun, other linear lightning or released during the ionization of atmospheric atoms. However, the number of newly arriving particles is significantly less than that originally acquired by it during formation. Therefore, there is a decrease in the number of ionized atoms due to their partial neutralization by ionizing particles that have lost energy. This is accompanied by a change in its brightness and color. With a significant size of the ball lightning, dark areas in the form of spots, channels, threads may appear in some areas, especially inside it. An extreme case is the staining of lightning before fading into black.

The explanation of the nature of ball lightning is one of the most fundamental problems of radiophysics and electronics, since none of the widely discussed theories of ball lightning can give an answer to the question about the source of the huge energy reserve that such lightning contains. According to one of the latest hypotheses, ball lightning isта plasma ball, the plasma in which is supported by ultrahigh-frequency electromagnetic oscillations inside this spherical resonator, at which these oscillations in turn are excited

Ball lightning can be observed quite often in natural conditions. The explanation of the nature of ball lightning is one of the most fundamental problems of radio physics and electronics. Recently, a large number of theoretical papers devoted to his research have been published [1, 2].

Ball lightning is a luminous spheroid with high specific energy, often formed after a linear lightning strike. An explosion causing destruction may accompany the disappearance of a ball lightning. The nature of ball lightning has not yet been clarified.

According to one of the latest hypotheses, ball lightning is a plasma ball. Plasma is a state of matter in which free electrons, positively charged atoms or ions and neutral atoms or molecules are present in the substance. Therefore, plasma is defined as a collection of charged and neutral particles [3-5].

In the simplest case, plasma can be represented as an ionized gas. But the gas is specific: it may contain charged particles that vary greatly in mass. Depending on the degree of ionization of atoms, plasma is conditionally divided into cold and hot. Cold plasma is a state of ionized gas in which the number of positively charged ions is negligible. Obviously, a large amount of energy is required to detach a large number of electrons from a multi-electron atom. In this sense, a strongly ionized plasma can be called hot. To describe its properties today, various models are often used. Several papers have been devoted to the calculation of temperature fields under various conditions [6-8]. In this case, the temperature dependence of the thermal conductivity of the plasma is often not taken into account.

2 Main Part

We will consider the lightning itself as a spherical continuous conductive ball with a specific electrical conductivity σ, in which all the electrical energy supplied to the unit volume is diverted due to thermal conductivity to the cooled walls of the sphere with radius R. The plasma energy balance is described by the thermal conductivity equation, which in a spherical system has the form [9]

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\lambda\frac{dT}{dr}\right)=-\sigma E^2 \tag{1}$$

where: λ is the coefficient of thermal conductivity, E is the electric field strength.

The following boundary conditions were taken into account: at r = R T = Tc, where Tc is the wall temperature. Also, due to symmetry, there is no heat flow in the center

$$\left.\frac{dT}{dr}\right|_{r=0}=0 \tag{2}$$

Energy is transferred to the surrounding space from the ball lightning due to thermal conductivity and radiation, and the latter plays a major role, so that it is possible for temperature dependence in accordance with the Stefan-Boltzmann law

$$q=\sigma T^4 \tag{3}$$

where: σ is the Stefan-Boltzmann constant.

When solving this problem, it should be taken into account that a heat source with a specific power of qv operates inside the lightning. To find the distribution of the temperature field, it is necessary to solve the Poisson equation [10]

$$\Delta T+\frac{q_v}{\lambda}=0 \tag{4}$$

expression (4) in a spherical coordinate system will take the form

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dT}{dr}\right)=-\frac{q_v}{\lambda} \tag{5}$$

let's separate the variables

$$\frac{d}{dr}\left(r^2\frac{dT}{dr}\right) = -\frac{q_v}{\lambda}r^2 \tag{6}$$

let 's integrate both parts of the equation

$$r^2\frac{dT}{dr} = -\frac{r^3 q_v}{3\lambda} + C_1 \tag{7}$$

let's separate the variables again

$$\frac{dT}{dr} = -\frac{r q_v}{3\lambda} + \frac{C_1}{r^2} \tag{8}$$

re-integrate both parts of the equation

$$T = -\frac{q_v r^2}{6\lambda} - \frac{C_1}{r} + C_2 \tag{9}$$

Constant C_1 =0 due to the final value of the temperature in the center. Therefore

$$T = -\frac{q_v r^2}{6\lambda} + C_2 \tag{10}$$

We find the constant C_2 from the boundary condition (3)

$$-\lambda\frac{dT}{dr}\bigg|_{r=R} = \sigma T^4 \tag{11}$$

substituting (10) into (11), we get

$$\frac{q_v R}{3} = \sigma\left(-\frac{q_v R^2}{6\lambda} + C_2\right)^4 \tag{12}$$

from where the integration constant C_2 is equal to

$$C_2 = \frac{q_v R^2}{6\lambda} + \left(\frac{q_v R}{3\sigma}\right)^{1/4} \tag{13}$$

then the law of temperature distribution will take the form

$$T = \frac{q_v\left(R^2 - r^2\right)}{6\lambda} + \left(\frac{q_v R}{3\sigma}\right)^{1/4} \quad (14)$$

From formula (14) it is possible to find the temperature of the ball lightning surface

$$T_c = \left(\frac{q_v R}{3\sigma}\right)^{1/4} \quad (15)$$

The formula (15) can be used to find the averaged stationary lightning temperature. Below is a graph of changes in the temperature field of a spherical plasma (fig. 1).

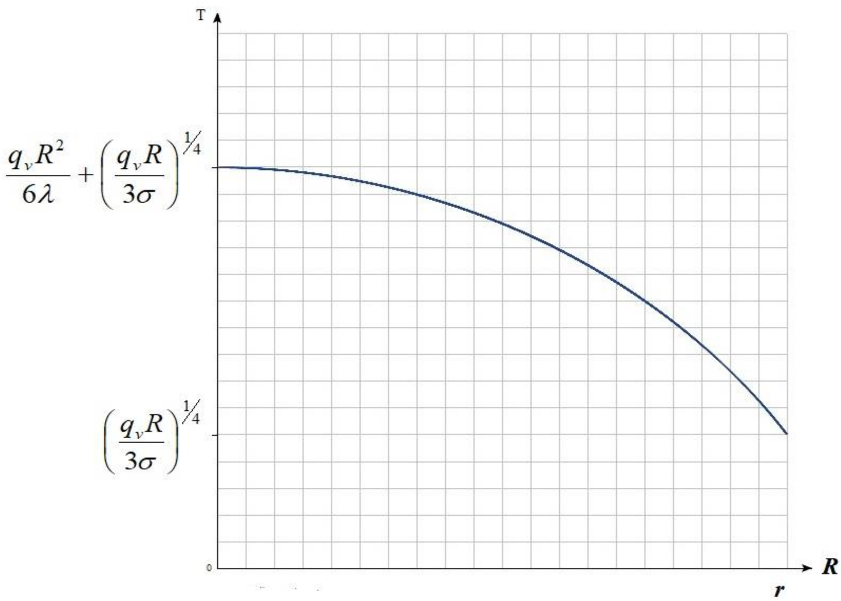

Fig. 1. Graph of the dependence of the ball lightning temperature on its radius.

3 Conclusions

The article is devoted to the study of ball lightning. The main purpose of the work was mathematical modeling of the temperature field of the arc of a conducting sphere under given boundary conditions. When finding a solution to the problem, heat losses due to radiation heat exchange were taken into account. As a result, the law of temperature change in the cross section was obtained, as well as a formula for determining the surface temperature. The result obtained can be used to study the properties of ball lightning.

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