PHYSICAL SCIENCES

BALL LIGHTNING: A MYSTERY OR A CLUE?

Kulakov A.
Corresponding Member of Russian academies Nauk Doctor of Physics and Mathematic Sciences. Institute of Functional Economic Systems, Moscow, Russia
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Abstract

The physical state of the substance of ball lightning (BL) is one of the most important problems of modern physics. The main issues are its stability, energy (about 30 kJ are released in one gram of CMM substance), the action of surface tension forces in a substance with air density and electromagnetic phenomena of an obscure nature - from electric sparking to radio emission and magnetic effects. The paper proposes a physical mechanism for the formation of BL based on the forces of a quantum nature, which are realized in a non-ideal but non-degenerate plasma. In the case when the de Broglie wavelength of thermal electrons, as the plasma temperature decreases, turns out to be several times smaller than the interion distance, the intercenter interference overlap of the electron wave functions becomes significant. Quantum forces generated by such an overlap "collectively" link the particles, the energy of the system decreases (its excess is radiated). The CMM problems posed at the beginning have been solved.

Keywords: liquefied plasma, plasma quantum condensate, interatomic interactions, quantum forces of attraction, exchange interaction of electrons

The usual linear lightning that accompanies thunderstorms is well known to everyone, as everyone also knows that it is a powerful electrical discharge. Scientists studying atmospheric electrical discharges also know the quantitative physical characteristics of linear lightning. The diameter of the discharge column is on average two centimeters, the gas pressure inside the discharge is about five atmospheres, the potential difference between the extreme points of the discharge can reach one hundred million volts (10 8 ^{V}). During the discharge, about ten coulombs of electricity pass through its cross section, so that the total energy in the discharge of linear lightning is a billion joules (10^{9} J.)

[1]. Thunder rolls are already a consequence of the discharge: the fiery discharge cord gives rise to a diverging cylindrical shock wave, which, weakening as it propagates, passes into an ordinary sound wave.

Sometimes, after strong thunderstorms, luminous spherical formations are observed with a duration of existence from several seconds to several minutes. These formations are called ball lightning.

Descriptions of eyewitnesses of the phenomenon of ball lightning have now accumulated a lot. It would take voluminous volumes to more or less fully reflect these descriptions. They were compiled, as they say, by ordinary people, by no means professionals in the field of atmospheric physics or the theory of electricity. Therefore, as a rule, they are subjective: the very style of presentation is often determined by the professional or psychological characteristics inherent in one or another observer. Here is how, for example, the famous artist N.K. Roerich describes ball lightning during his journey through Central Asia: “... at a high altitude, something brilliant moves in the direction from north to south. Binoculars were brought from the tents. We observe a voluminous spheroidal body, sparkling in the sun, brightly visible against the blue sky, which is moving very quickly. Then it hides behind a snow chain."

It is felt that the observations belong to the artist. It is also worth noting that the above description of ball lightning, if transferred to the soil of modern hobbies, would completely coincide with a typical description of an unidentified flying object - a messenger from other civilized worlds. Nevertheless, definitely, we are talking about the observation of ball lightning following a lightning discharge.

The reliability of the very fact of the occurrence of ball lightning is no longer in doubt. But even at the beginning of the 20th century, many scientists refused to consider eyewitness accounts, did not accept this phenomenon as existing in nature. The phenomenon itself was declared to be fictitious, seeming due to the " aftertrack " imprinted on the retina of the observer's eye from a flash of ordinary linear lightning. However, the extensive and patiently collected material based on the descriptions of eyewitnesses, the study, so to speak, of the material traces left by lightning, and most importantly, the observations and descriptions of the scientists themselves, cast the last doubts into dust, and the matter moved into the mainstream of scientific analysis, explanation of the phenomenon and the creation of a convincing hypothesis, allowing to understand what it is - ball lightning.

Before considering the theoretical interpretations of the phenomenon of ball lightning, let us turn once again to eyewitness accounts that give its figurative representation, a clear picture of its development and disappearance. We will select only some of the descriptions given and commented in the book [1]. Here is one of them:

“It was a hot day. By evening a storm had gathered. A group of boys was returning from the Mias River and saw how, at a height of 8-10 meters above the houses, a fireball 30 cm in diameter crosses the street. The ball, as it were, consisted of individual multi-colored stars. It moved smoothly, and a tail of sparks moved in the opposite direction. The ball crossed the street and hung over the houses. Then it disintegrated into bright sparkling fragments, illuminating the house with radiance.

We also give the following description of an eyewitness: “After a peal of thunder, two white balls with a diameter of ten and twenty-five centimeters flew through the chimney. They flew at a speed of two or three meters per second at a low height from the floor. The balls flew into the middle room and went along the walls to the wall between the two windows, where the grounding was carried out. Flying up to the wire, the balls stretched out, turning into ellipses, and, touching it, silently disappeared into the hole in the floor. As they moved along the wire, a slight crackle was heard.

Once, ball lightning appeared after a strong thunderstorm in the Arkhangelsk Cathedral of the Kremlin and was swept (literally) by an attendant outside the door of the cathedral. Sometimes, however, this kind of attack on the lightning ball ends badly: the lightning explodes with a strong roar, injuring people who were nearby.

In a small French town there was a tragicomic episode associated with the appearance of ball lightning. She appeared after being struck by ordinary lightning and entered the kitchen of one of the houses through a chimney and a fireplace. The fireball was at the feet of the young owner of the house. The women who were in the kitchen advised him to crush "this abomination" with his foot. However, he instinctively understood the danger of careless experiments with mysterious manifestations of electricity and refused to trample ball lightning with his foot. Meanwhile, the ball rolled out into the yard and there a pig tried to sniff it - the ball exploded. Disrespect for electrical matter cost the last life ...

Here is an excerpt from a letter sent by a young Frenchman to L. Arago , a researcher of the phenomenon: “A huge lightning flashed in the middle of the street, followed by a blow like an artillery salvo. The hat, which was thrown back by the wind and the shocks produced by the electrical explosion, I caught and went on without incident. Everything was limited to the fact that my stomach could not digest food for two weeks.

A careful study of eyewitness accounts (this phenomenon has not been obtained in a controlled way in laboratory conditions) allows us to exclude all those distortions that are associated with emotional or stress factors due to simple fear of the incomprehensible, and to imagine some average picture of the phenomenon.

Ball lightning, as a rule, is a luminous ball with a diameter of 10-30 cm. The color of the radiation is predominantly white, but with a wide variety of shades - from orange-red to yellow and even purple. The ball glows like a 100-watt light bulb. Burns, charring, produced by ball lightning during direct contacts, indicate that the temperature of the ball hardly exceeds 600-700 degrees (on the Celsius scale). Accidents are quite rare and are usually associated with the hit of ball lightning in the uncovered head of the victim (lightning, apparently , is attracted to the hair of the head). Therefore, ball lightning can be observed relatively calmly, without showing excessive activity.

The energy stored in ball lightning is on average twenty kilojoules. Per unit volume, this is about 0.2 kJ/cm^3. The density of matter in lightning is approximately equal to the density of air $1.3 \cdot 10'^3 g/cm^3$, hence we get the so-called specific density of energy content in ball lightning ~100 kJ/g, a value exceeding the specific density of energy release in explosives such as trinitrotoluene. One gram of the substance contained in a "typical" ball lightning and one gram of dynamite produce approximately the same effect. That is why the explosions that sometimes occur with ball lightning lead to deafening pops that frighten the observer.

Ball lightning has some peculiarities. It seems to be striving for enclosed spaces, penetrating into them through disproportionately small cracks, "floats" in the air and is attracted to metal objects, open tubs of water, chimneys.

The lightning ball is light, it literally “floats”, carried away by the slightest movement of air, and at the same time causes a number of electrical and magnetic phenomena. Its movement is accompanied by a characteristic crackling and scattering of sparks, as in an electrical circuit during a short circuit. The ball "scents", creating a special dry smell of an electrified and ozonized environment. Finally, the ball creates a fairly strong radio emission, suppressing all-transistor radio reception within a radius of up to one hundred meters.

Yet the most important and intriguing feature of the lightning ball, at least in terms of physics, is its amazing stability. The discharge of linear lightning that creates this ball lasts no more than 0.1 seconds. Approximately during the same period of time, at the cost of enormous efforts, it is possible to "keep" the plasma in tokamaks - installations designed for thermonuclear fusion. A spherical discharge (if it is really a discharge) “lives” thousands of times longer, and, apparently, completely autonomously, without any support “from outside”. There are no energy-supplying elements such as waveguides and contacts with sources. And even if such an invisible pumping, for example, in the microwave range of waves, would take place, then, as simple calculations show, the supplied energy should be more than a thousand times greater than the energy contained in the ball. And this is in addition to the inevitable difficulties associated with suppressing the instability of the ball.

What is ball lightning? In the 19th century, the French physicist Arago , the first systematizer of materials and researcher of ball lightning, wrote about its structure in the following way: "ball lightning consists of oxides of nitrogen and ozone and is impregnated with lightning matter." What it is - lightning matter - the scientist, however, did not explain.

Objects that look like ball lightning are sometimes obtained randomly when experimenting or working with powerful electric batteries. So, for example, when replacing batteries on a submarine, such an object arose [2]. in a battery with

voltage of 200 V and a current of $1.5 \cdot 10^5$ A, a short circuit of duration 0.01 sec was formed, as a result of which a luminous ball arose, which lasted several seconds before its collapse.

It is easy to estimate the energy of the resulting discharge with a diameter of 10 cm. With a source power of 3 ·10 ^{7} W, energy of 3 10 ^{5} J is released during the discharge . The energy density in the ball is 0.3 kJ/cm ^{3} in this case . The corresponding energy density in trinitrotoluene is 2 kJ/cm ^{3}. However, the density of matter in the latter is about a thousand times higher than in a gas discharge. Therefore, the specific energy density in the latter is higher than in explosives. This means that the forces of molecular cohesion in the substance of ball lightning are very high.

Phenomena similar to ball lightning, but on a larger scale, are observed in the atmosphere during strong earthquakes, or rather, immediately before them. Such a phenomenon took place a few minutes before the earthquake in Tashkent on April 25, 1966. According to the description of the seismologist V.I.Ulomov, the following happened. About half past six in the morning, when the sun was still below the horizon, a giant fiery torch burst out of the ground with a hiss and soared over the roofs of the houses. Quite clearly defined at the edges and blurred at the top, it expanded, resembling the flame of a colossal candle. It illuminated the silhouettes of houses. Under the influence of its radiation, fluorescent lamps on the streets spontaneously ignited, wires sparkled, overvoltages of electric fields of 5-10 kV ÷were recorded in underground cables [3].

Quite

it is possible that there is some causal relationship between formations such as ball lightning and physical agents that cause tremors.

Until now, ball lightning has been a mystery to physics. Mastering this secret will undoubtedly lead to new technical discoveries and achievements in energy, electronics, and electricity. Perhaps the disclosure of the physical nature of ball lightning will help to understand the mechanism of cataclysms occurring in natural conditions, such as earthquakes, stellar flares and cosmic explosions. Let us turn to a review of hypotheses explaining the phenomenon of ball lightning.

The group of hypotheses is based on the idea of chemical combustion of the substance of ball lightning. This idea was first put forward by Ya. I. Frenkel. With a suitable chemical composition, ball lightning is ignited by a discharge of ordinary lightning, and then its combustion is supported by chemical reactions. This combustion is especially effective if a sufficient amount of ozone is concentrated in the lightning ball. Indeed, it is well known that the smell of ozone is clearly felt near ball lightning. True, it is very unclear how the necessary chemical concentrate is formed in natural conditions in a volume of 1-3 dm ^{3} and why it does not dissipate before being set on fire by lightning.

In modern modernized theories, they try to get around this difficulty, believing that ball lightning is not just a chemical, but an ion-chemical reactor. The energy release is due to the reactions of the oxonium compound with the hydroxyl group with the formation of water vapor: $H_3O^+ + OH^-$ - $2H_2O$ + 10 eV. Oxonium is "harvested" in a thundercloud, so that the difficulty associated with chemical supply is essentially removed. Assuming the concentration of ionic complexes equal to the Loschmidt number (2x10 ^{19} cm- ^{3}), and the volume - 1 dm ^{3}, we obtain the energy yield of ball lightning equal to about 30 kJ, i.e. just the size of its average energy reserve . The specific (calculated per 1 g of substance) energy release is approximately 30 kJ/g, which is almost exactly equal to the specific heat of combustion of anthracite. A conglomerate of ions with charges of different signs is a plasma. In a substance in the plasma state, electric and magnetic fields are relatively easily excited, which are actually detected (directly or indirectly) in ball lightning. It would seem that everything is well explained in the considered physicochemical hypothesis. However, there is one radical flaw in this hypothesis, which essentially reduces it to nothing. It turns out that the duration of chemical reactions, as well as recombination processes, in which electrons combine with positively charged ions, does not exceed fractions of a microsecond, while the duration of the existence of ball lightning reaches tens and hundreds of seconds (up to 5 minutes).

IP Stakhanov considered the possibility of formation of ion clusters - "soldered" groups of molecules, in the center of which there is an ion, the electric field of which is shielded by a molecular shell. In this case, the electrons are decelerated by the shell - the recombination process is delayed in time. However, in this case, the molecules of the cluster shells represent a ballast that makes the entire sphere of clusters heavier and reduces the efficiency of chemical reactions.

The complex of electromagnetic phenomena observed in ball lightning was explained by P. L. Kapitsa's waveguide hypothesis . According to this hypothesis, ball lightning occurs in the antinodes of the radio wave field with a wavelength of 40 - 80 cm. The antinode has a linear size equal to a quarter of the wavelength, i.e. like the size of a fireball. To ionize the air and excite the observed glow, energy flows of the order of megawatts per square meter are needed. Such streams in the radio wave range can be generated by linear lightning. However, in this case we would observe chains of antinodes (as in a waveguide), and fireballs always appear individually. In addition, the sphinx of energy control is again active. During the lifetime of the ball, a hundred times the actual energy would have been pumped into it: observers would immediately assume that, fortunately, this is not happening.

The stumbling block for many hypotheses considering the nature of ball lightning turned out to be the fact of its amazing stability. As a holistic formation, it “floats” in the atmosphere at a distance of several hundred meters, bypassing or overcoming various obstacles, enters houses through narrow cracks, as if pouring into a hole, while completely restoring its original shape. It always disappears unexpectedly or quietly, as if melting in the atmosphere, or, on the contrary, with a powerful acoustic effect in an explosive way. The temperature inside ball lightning can apparently reach a thousand or more degrees (on the Celsius scale). Nevertheless, it does not spread through the air for quite a long time , holding back internal tension forces. It is these forces, such as the forces of surface tension in a liquid, that represent the main mystery of ball lightning. In modern concepts, the emphasis is on explaining precisely these forces.

In the model proposed by B.M. Smirnov , it is assumed that coal dust burns in ozone in the volume of ball lightning. Tension forces are due to the central charge. According to Earnshaw's theorem , no configuration of charges can stabilize a system unless additional forces of non-electric origin are applied to it. Therefore, it is assumed that the balance is provided by a rigid openwork frame - a kind of reinforcement made of metal compounds enclosed inside the lightning sphere. In addition to the difficulties associated with the chemical "support" of such a model, there are, of course, difficulties in the formation and simultaneous coexistence of two such heterogeneous subsystems.

The concept of ball lightning, which is proposed in [4.5],

is purely quantum. It considers the possibility of the formation of a very large molecule (supermolecule) in a plasma conglomerate of ions and electrons. Ball lightning is one such supermolecule .

Coulomb forces acting between charged particles are known to be long-range. This means that they decrease with increasing distance between particles most slowly of all known forces (however, according to the same law, gravitational forces also change with distance, but the latter are essential for cosmic masses). In an ionized gas, which is considered by modern physics as the fourth state of aggregation of matter - plasma, the Coulomb forces are screened during the thermal motion of background plasma particles at the so-called Debye radius, so that outside the sphere of this radius, this charge practically does not create a field in the plasma (more precisely, this field decreases exponentially with distance).

What is new here in quantum mechanics? Let the wavelength of the De Broglie electrons (equal to the quotient of Planck's constant divided by the average value of their momentum) be comparable, but still less than the average distance between the particles. Then the forces of quantum nature are "switched on", which are associated with the overlapping of the electron shells surrounding the plasma ions. Of course, these shells are rather friable, since the electron cloud (whose intensity determines the probability of finding a particle at each location) extends over the area of the Debye sphere, the radius of which, as a rule, greatly exceeds the interelectron distance. However, the volume of the overlapping regions of the shells also increases accordingly. In molecular compounds, on the contrary, the cloud intensities are higher, but the sizes of the overlapping zones are also smaller. On the whole, in both cases, quantum forces lead to mutual attraction (and not to repulsion, as is the case in the classical case) of electrons, and through them the forces of attraction are transmitted to the atoms. This is how molecules are formed, stronger complexes - excimers and clusters, and, finally, macroscopic complexes of particles in plasma. Typical binding energies calculated for one electron-ion complex reach values of 10 electron volts . And since statistically an average lightning ball contains about 10^{23} such complexes in its "womb", it is not difficult to obtain from this the energy content (or heat of "combustion") of ball lightning - about 100 kJ.

So, ball lightning is formed not as a result of some chemical or electromagnetic process, but as a result of a special kind of phase transformation that occurs in low-temperature plasma. These processes are characterized by a rather large energy release of a quantum nature. It is she who causes the electromagnetic radiation of ball lightning. In this case, the state of matter in it turns out to be bound, which causes the emergence of tension forces that maintain the balance of ball lightning. This is the quantum model of this formation.

There is no doubt that the phenomenon described here and its interpretation will make it possible to master it in technology, and, perhaps, to obtain an effective and original source of energy.

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