

Analysis of Mechanical Traces Left Probably by Ball Lightning

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ABSTRACT

A possible ball lightning (BL) incident, reported in a local TV as a thunderbolt which during heavy storm entered the room through one of windows and left it through the other, is analyzed. Precise reports, concerning the course of the incident and caused damages, were collected over the next few days in talks with seven eyewitnesses. To verify the reports, photographic documentation, pieces of the window panes, front-window meshes and other fragments of damaged objects were collected simultaneously on the scene. Reconstruction of the glass panes in the laboratory and analysis of Wallner lines existing on surfaces of radial cracks of the panes enabled to identify the direction of force causing the pane breakage. Since the forces turned out to be external for both windows, it excludes the reported movement of BL through the room. From the analysis of traces, the object which destroyed the window pane from the outside should have the following properties differing from those of an ordinary stone: it should be able to break the mesh mechanically on a small circular area, then becoming a larger and softer object be able to push the glass pane forcefully and violently. BL may be responsible for the damages if a solid-like non-hot BL core, capable to explode, is assumed. It is postulated that the BL core is composed of positively-charged crystalline nanoparticles of covalently-bonded nitrogen ions N^+ and electron gas inside.

Keywords: ball lightning; field research; glass fracture; trajectory of movement; electrostatic forces; solid nanoparticles

INTRODUCTION

Ball lightning (BL), also called fireball, is an intriguing enigma far from a complete explanation [1]. In the published literature [1-7], many reports of the people, who had an opportunity to observe the mysterious fireballs typically during thunderstorms, have not allowed to establish their nature. This can be attributed to rarity of the phenomenon whose observation is shared by only 0.4% of the people during their life [3]. Therefore, chances for any planned observation of the fireball are very small. Thus, descriptions of this phenomenon come usually from non-professional observers, often startled by this unusual phenomenon. Such short and unexpected observations rarely result in a more detailed description of the object than specifying its size and color, while other more detailed reports do not give a consistent picture of the BL properties.

The source of information on the appearance and behavior of BL may be newspapers, magazines and electronic mass media. This is due to the fact that, in the summer season, news devoted to violent storms are a fixed point of information programs in these media in many countries. Sometimes, one can find information about the appearance of a ball lightning, if it reaches a journalist. Unfortunately, as seen from the history of a case of a BL in Armenia commented critically by Smirnov [3], some of these reports can be unreliable and are often simply fabrication of a witness or a journalist chasing sensation. An example of this human attitude can be found in the article [8] in a local newspaper describing in details a fireball which "...came inside a room through a chimney, devastated the room, covered all inside by soot ... and escaped by the chimney" (short summary) in one of houses in a village of 900 inhabitants located 75 km from Lublin (Poland). After reading this news,

the author went immediately twice to the village to find the site of the described appearance of the BL and to meet witnesses. The information obtained directly from a person (an important local official), who provided the description of the event to the press journalist, allowed to find the described house. The home owner, however, denied that such an event had happened in her house, informing that the upper part of the roof of her house was only slightly damaged several days ago by an ordinary lightning strike to the building. There could be only one conclusion from these on-the-spot checks that the event described in the newspaper has not happened in the village.

Cases of fabrications of BL observations are possible when they are not critically verified as soon as possible. Suspected examples of eyewitnesses' reports are, in the author's opinion, those describing in three different stories that the BL is able to evaporate golden chain, bracelet or metal ring in a very short time. Nikitin et al. [6] interpreted the disappearance of metal objects to be caused by a high-frequency electromagnetic field emitted by the BL in 0.01 s, which led to very fast heating of the metal until its evaporation. No explanation was given in the article, why such powerful impulse of the electromagnetic wave had not led to the killing an eyewitness or, at least, to leaving any extensive burn wounds on his/her skin. Singer [9] remarked that only a small number of BL observations had been investigated to determine the reliability of eyewitnesses. In order to do this, one should reach the scene as quickly as possible and document there the relevant information directly from the witnesses for a critical and scientific analysis. In the author's opinion, it must be accompanied by a thorough analysis of material traces left by the analyzed BL. This is in accordance with Charman's suggestion [2] for the creation and use of a more subtle variant of questionnaire as well as for physical and chemical studies of any after-effects such as damages or material deposits.

The aim of this work is to analyze carefully an intriguing incident during a violent storm, reported in TV but also investigated on scene by the author. It is to present significance, even advantage, of the physical analysis of material traces, left possibly by a BL, in comparison with the eyewitnesses' reports. Therefore, research methodology is based not only on collecting information from eyewitnesses with their critical analysis, but mainly on analysis of mechanical damages with the scope to create a consistent description of the incident. The

analysis of the traces also give an opportunity to determine possible physical properties of BL and formulate a hypothesis on its chemical composition and/or internal structure. The hypothesis advanced here is briefly compared with several of the BL models among the many proposed so far (see the most extensive presentation of BL models [1] or the latest one in Refs. [7, 10]).

METHODS

An interesting incident took place in Rozkopaczew (pronounced as: rɔskɔ'patʃɛf, a village situated 30 km north of Lublin) on 10 August 2001. Local Lublin television reported [11] on the next day that in one of the buildings of the village "a thunderbolt fell into the room through one of windows and left through the other" and showed a film illustrating the damaged windows accompanied by reports of some witnesses. A day later the author heard about this incident from one of the TV viewers, he was able to locate the scene (i.e. a farm) in order to collect the first witnesses' accounts three days later after the incident. During several next visits the author documented on film and photos damages of the farm buildings caused by the storm and by the hypothetical thunderbolt/lightning and took samples for laboratory tests and analysis. Unfortunately, significant contradictions between eyewitnesses' reports and material evidences made the interpretation of the incident very difficult and moved the time of publication of these results for a long period of 20 years. However, their presentation may still be interesting because of the atypical incident, careful examination of traces in addition to witness accounts, and the conclusions on some physical properties of hypothetical ball lightning, which could explain the observed damages.

A group of 10–12 people, during a violent afternoon thunderstorm stopped working and sought shelter in a small utility room (19 m²) located at the end of a garage (Fig. 1). When they ran through the backyard, heavy rain was falling, strong wind was blowing and numerous lightnings had started to strike. Shortly afterward as they had gone into the room, two room windows were broken almost simultaneously. The people were convinced that it was caused by something passing between them through the room from the window B to A (see Fig. 2). After the storm when they left the room, they saw in the front-window mesh (serving to stop flying insects)

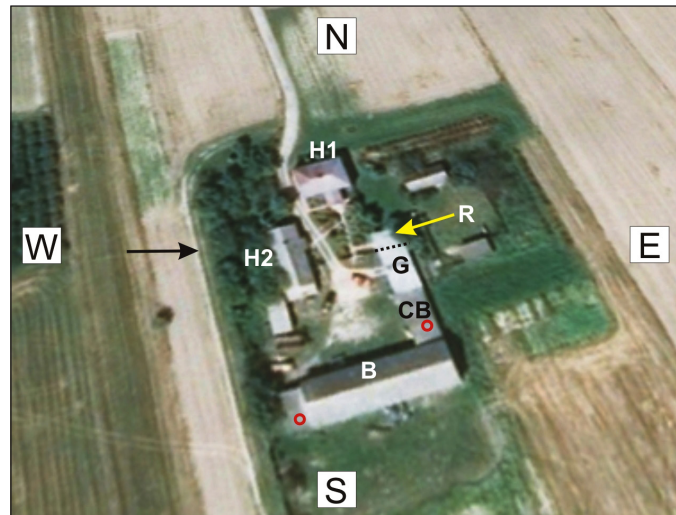


Fig. 1. Location of buildings on the farm as visible in the Google Earth Database: H1 and H2 houses, B barn, CB cow barn and G garage. Black arrow shows the wind direction, while yellow arrow points the location of the room (R) with eyewitnesses. Red circles point the location of holes in roofing made possibly by linear lightning strikes.

attached to the window A a mysterious rounded hole (Fig. 3) done, as they interpreted, by a thunderbolt. Such a report was shown on TV, which was broadcast in the evening of the next day. In the TV report, apart from showing the extent of the damages to the farm buildings, among others, with shots of the broken windows, emphasis was placed on the great danger which threatened so many people when the thunderbolt had fallen into the room.

In order to gather precise reports of the eyewitnesses the author prepared a detailed questionnaire containing 33 questions concerning the course of the event and the characteristics of the object that caused damages to the windows. He was able to collect answers to these questions from seven eyewitnesses. As a group, they expressed the deep belief that the thunderbolt flew very fast on a curved trajectory through the room from the window B to A

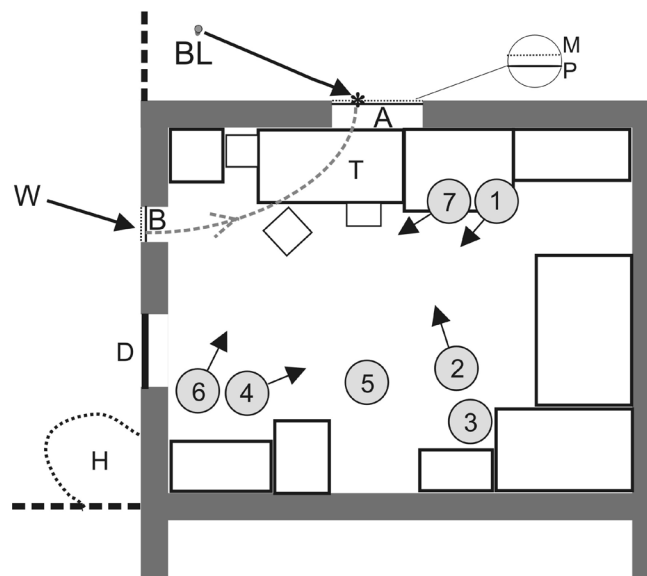


Fig. 2. Plan of the room with location of: window A and B, door D, table T and the witnesses (each marked by circle) with their view direction (arrow) during destruction of the windows panes. Location of the window mesh M in respect to the pane P is shown in magnification. Directions of the wind W and the hypothetical ball lightning BL (deduced from material signs) are illustrated by arrows, while hypothetical trajectory of BL from window B to A, according witnesses' reports, is marked by dashed curve. Location of the hole in the window glass (star), hole in the ground H and fence (dashed thick line) are shown.

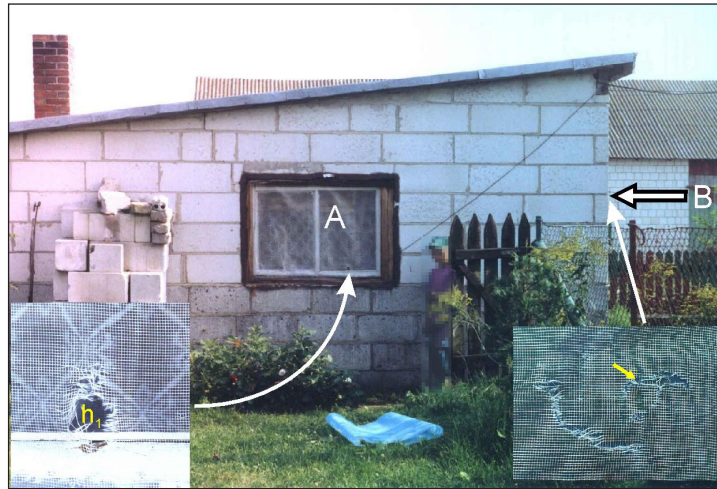


Fig. 3. View from the north to the building, where witnesses stayed, showing the window A with re-attached original anti-insect mesh and location of the window B on side wall. In insets are visible fragments of the meshes with holes created during the storm with the rounded one h1 from window A caused probably by ball lightning.

(see Fig. 2) fortunately skipping people. However, when questioned during individual talks, nobody confirmed to have seen or felt the movement of an object. Moreover, they could not explain why net curtains on the windows inside the room have not been bored by the thunderbolt though they confirmed that both windows had been covered by the curtains during the incident. According to the answers to the questionnaire, the window panes A and B were almost simultaneously broken just after witnesses enter the room, but two of them were sure that window B was broken first. After having heard a typical sound of breaking glass panes accompanied with hiss or swishing noise (4 among 7) or a bang (1 among 7), glass pieces from both windows were thrown into the room. One person even stated to have seen red glow in the window A during the break.

Observation of the surrounding area revealed large damage on the farm caused by the strong wind. A large part of the roof covering the cow barn was thrown away while the roof of house H2 and, to a lesser extent, in part of barn B (see location in Fig. 1) showed in numerous places torn, broken or bored large corrugated asbestos tiles. In one of the asbestos tiles on the cow barn roof, ca. 15 meters from the described room, the author found a round hole of several cm in diameter (the hole shape shown in camera snapshots in Fig. 4a), which could arise as a result of ordinary lightning stroke. More difficult for explanation is a large hole in the roof of the barn associated with two satellite small holes (see Fig. 4b). As a result of destruction of the roofs in buildings H2 and CB (see Fig. 1), numerous pieces of broken

asbestos tiles were cast in the backyard and in the East of the cow barn. Several small pieces of the asbestos tiles from house H2 were also stuck in a fairly soft plywood covering the external side of the door close to the window B.

The author inspected carefully parts of the two windows in the utility room including: remaining pieces of the broken panes, wooden window frames and the front-window meshes. The latter ones, as damaged during the storm, had already been removed by the owners, but were fitted again to the window (see Fig. 3) to restore the state right after the event. The lower, internal part of the wooden frame of the window pane A was chipped off producing a splinter of the length of over 20 cm (Fig. 5a).

On the outer side of the frame from the window A the author found pounded an irregular pebble (see Fig. 5b) with a mass of 4.0 g and sizes $2.8 \times 2.1 \times 0.7$ cm, which in its composition resembled a piece of mortar. The pebble pierced the mesh as evidenced by mesh glass fibers found after removing the pebble from the cavity created during the hit in the wooden frame mounting the pane. Die-cast of the cavity retained these fibers, but also allowed to determine the volume of the hole to be about 0.8 cm^3 . Comparing the position and size of the pebble and the shape and size of the hole in the mesh (see left inset in Fig. 3) it could be concluded that at least two objects passed through the mesh in close proximity: the pebble and something else with a diameter of not more than 5 cm. From the inclination of the hole in the wooden frame, the direction of movement of the pebble during the hit as 25° with respect to

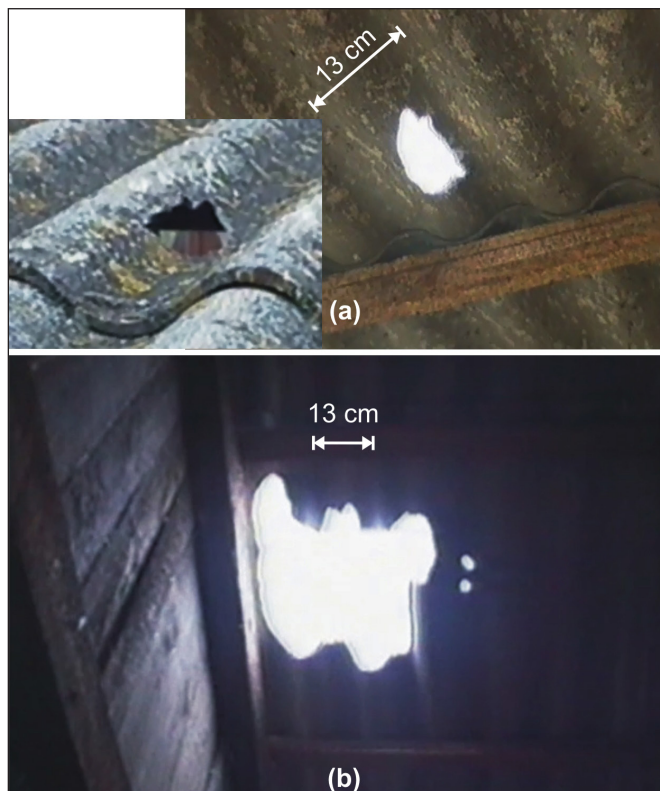


Fig. 4. Camera snapshots showing holes in asbestos tiles found in the farm on the roof of: (a) cow barn as seen from above (left) and from inside (right), and (b) barn from inside.

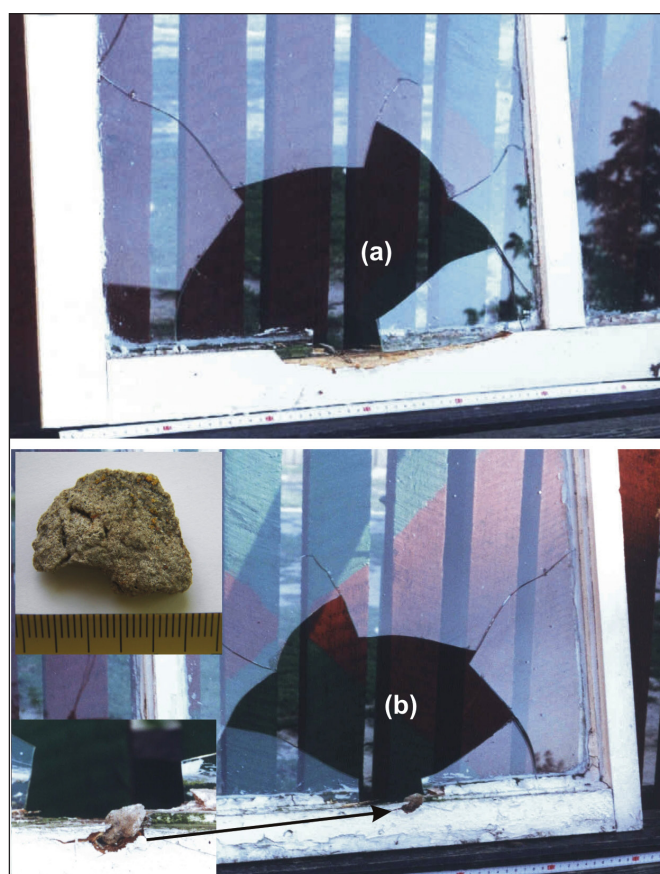


Fig. 5. View of the dismantled window A: (a) internal part with torn off a large piece of wood from the bottom of the frame, (b) external part with pebble driven in the wooden frame (magnified in inset). Upper inset photo shows the shape and size of the taken-off pebble.

the plane of the window pane (see Fig. 2) and 40° to the horizontal line (cp. Fig. 5b) was estimated.

There was one rounded hole in the mesh A with torn away fibers (left inset in Fig. 3), but the number of holes in the mesh B (right inset in Fig. 3) was greater even though the surface of the window B is smaller about 2.5 times. Moreover, the holes in the mesh B are much more elongated, but the torn away fibers are practically absent. All holes in the meshes A and B have the characteristics of mechanical damage. There are no signs of high temperature or burning. This can be deduced from the fact that parallel mesh strings (their diameter is 1 mm and separation 2.5 mm), made of braided glass fibers and strengthened by a flammable plastic, were cut or thrown instead of being melted or burnt.

During the period from the incident to the author's arrival to the spot, fragments of the broken window panes were picked up by the owners and collected in one container to be thrown away as garbage. During the inspection, the pieces of the glass panes A and B (their thickness is 3.9 mm) that were still embedded within the window frames were taken out. All collected fragments, without any cleaning, which might destroy possible traces on their surface, were used later to reconstruct two glass panes in order to determine the location and type of impacts.

In the case of the window A, the reconstruction is almost complete, since only three small fragments are missing (see Fig. 6a). Some fractures propagate from the point P_1 on the edge of the windowpane located at the point where the pebble was driven to the pane frame (cp. Fig. 6a and the inset in Fig. 5b). However several cracks originate from another point P_2 located 3.0 cm above the point P_1 .

The glass of the window B was much more difficult to reconstruct because it cracked to many small pieces and some of them were even not found. Nevertheless, a dominant portion of the pane B was reconstructed enabling the location of the impact site pointed by arrow in Fig. 6b. Fragments of the broken pane B near this hypothetical impact point were too small to be collected by the owners or arranged properly during reconstruction.

The direction of impacting body can be deduced from the shape of ridge lines (Wallner lines), i.e. many characteristic curved lines formed on the surface of radial cracks as is shown in inset in Fig. 6b. Formation of these characteristic lines is due to different velocities of crack-front propagation near tensile side or the compression side of a cracking slab [12]. One end of the ridge

line is always perpendicular to the glass surface opposite to the impacted glass surface (see inset in Fig. 6b) as it is expressed by 4-R Rule [13]. Applying the rule, it was found that fractures in both window panes are typical for the impact on the pane from outside.

RESULTS

It is known from the literature [13, 14] that cracking of a glass pane near the center of an impact point leads to the formation of radial cracks/fractures, propagating from the center, and concentric fractures surrounding the impact point. Shapes of fractures in the window glass B (Fig. 6b) are very similar to those shown in the manual [13] as caused by a blunt object. The large fragment of an asbestos tile, brought by the wind blowing from the building H2 (see Fig. 1), can explain the glass destruction. The elongated and curved shape of the largest hole in the mesh B (see right inset in Fig. 3) suggests that it could be initiated by cutting on sharp edges of the concentric fracture and torn by the asbestos fragment impacting the window glass through the hole in the mesh pointed by yellow arrow in Fig. 3.

In the case of the pane A, some radial cracks propagating from point P_1 terminate at point P_2 (see Fig. 6a), where new radial cracks originate, which, as judged from their directions, could not be initiated at P_1 . This suggests, if not confirms, that the pane breaking was initiated in two points P_1 and P_2 practically at the same time. Since the pebble hit and stuck in the wood frame, it could only initiate cracking of the pane from the point P_1 located on the glass edge near its impact point (cf. Fig. 5b and 6a). The pebble alone was not able neither to push the glass fragments into the room nor to tear off the above mentioned large splinter from the frame inside.

It was a serious problem to explain what type of body/object could make the main hole h_1 in the mesh and probably initiate pane breaking at point P_2 . There are four arguments which exclude that it can be a solid object such as another larger stone moving together with the pebble, hitting first the mesh and then the pane A. Firstly, the distance between the mesh and the pane surface, accompanied with the small impact angle observed for the pebble, should result in a horizontal shift of point P_1 and P_2 , what is not visible in Fig. 6a. Secondly, a

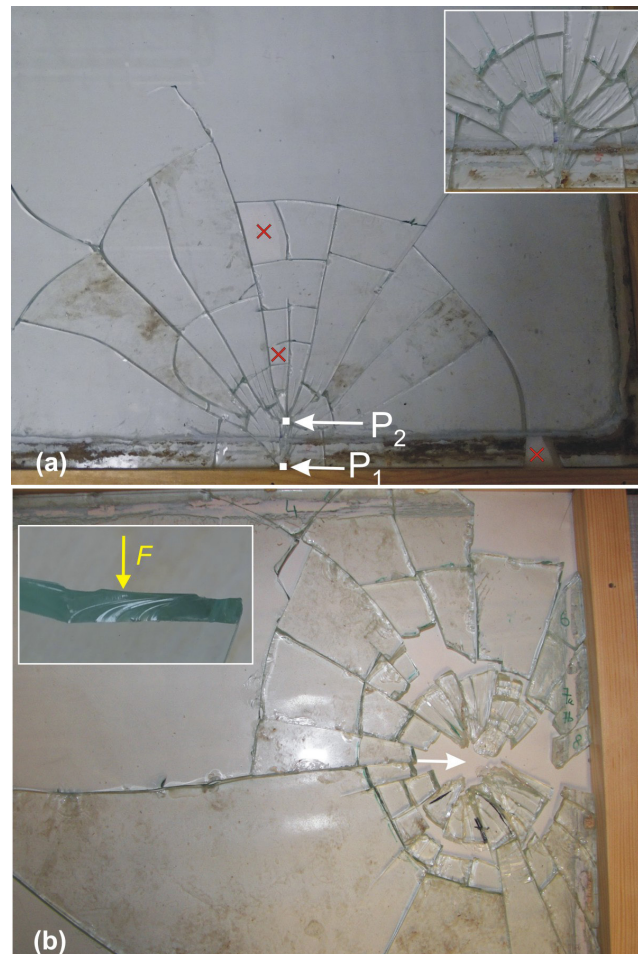


Fig. 6. Reconstructed glass panes from window: (a) A, and (b) B. Three missing fragments of the pane A are pointed by red cross. Two origins P₁ and P₂ of radial cracks in the pane A are marked by white squares pointed by arrows. In the case of pane B an arrow points the unique crack origin. Upper inset shows a magnified picture of the cracks in the pane A, while bottom one demonstrates shapes of the Wallner lines at the surface of a radial fracture caused by a perpendicular force F. Some collected fragments of the broken panes become dirty by soil particles.

fast-moving solid object is expected to break the glass pane smashing it into tiny parts in the impact center, what is not observed in the reconstructed pane A. Thirdly, the relatively small body of 5 cm in diameter cannot transfer a great momentum to the pane pieces (some thrown far into the room as witnesses reported) and tear off the large splinter. Fourthly, such a solid body or stone is expected to fall into the room, where it should be observed.

The body or object which destroyed the window pane A at point P₂ should have unusual properties. It should be able to break the mesh mechanically on a small circular area moving along with a stone at high speed, and then becoming a larger and softer object, it should be able to push the glass forcefully and violently to break it without smashing the glass into tiny parts. The exerting

force had to be strong to break away the long splinter mentioned above and throw some glass fragments far inside the room. Probably during the collision were emitted sound waves similar to those of fired flares or a whistle. Absence of any signs of burning or melting of the mesh fibers and non-charred lichens, preserved on the pebble surface, excludes the existence of a high temperature or burning of such object. It is likely that the object has been completely decomposed because no residues of any object were found between the mesh and the window or inside the room.

To explain the event, an idea of a high-speed BL hitting the mesh and the window glass A is used here. As in some models [3, 15-17], it is assumed here that the BL has a solid core. The author's hypothesis is that the BL solid core is in the form of many positively charged crystalline

nanoparticles (Fig. 7), which can aggregate with one and another, “glued” together by air anions and electrons into many microparticles similar to those of a dust. The novelty here is the assumption that each BL nanoparticle is a spherical, crystalline object (Fig. 7b) made from ionized nitrogen atoms N^+ linked by covalent bonds to the diamond structure (Fig. 7c). Since at normal conditions the stable form of nitrogen is diatomic gas, the possibility of occurrence of an explosion is expected in the form of violent phase transition from the metastable N^+ solid to the N_2 gas, when mechanically disturbed.

Explanation of the event leading to the mysterious damage of the window glass A can be as follows. In the fragment of plasma channel, probably in the form of a loop, of one of the linear lightnings during the thunderstorm solid particles are created from ionized nitrogen atoms N^+ . Then, the formed BL falls down in the gravitational field dragged by the wind of a high speed. As this BL is composed of a positively charged particles, it can be pulled and accelerated by the electric field from negative charge of many electric discharges when they are spreading over ground [18]. During the motion of this charged mass in the air or in contact with the wall of a building, the BL core encounters and attracts a piece of mortar by electrostatic forces acting between positively-charged core and the polarized mortar/pebble. Then the BL core with the

attached pebble is accelerated to a relatively large value by the negative electric charge striking the building with the witnesses inside. After hitting and piercing the mesh, the pebble hits the window frame and sticks in it initiating several radial cracks at the windowpane edge at the point P_1 (see Fig. 6), while the BL core is destroyed rapidly turning into positively ionized nitrogen gas. Explosive destruction of moving BL core during contact with the mesh in the window A, strengthened by a kinetic energy, including possible core rotation, can be responsible for a mechanical destruction of the mesh. Due to large forces of interaction with negative charges on the ground or on the building, prior to the total electrical neutralization of the gas, it pushes the bottom of the pane leading to its breaking at the point P_2 . The forces are high enough to break off 20 cm long splinter of the wooden window frame (see Fig. 5a) and throw glass fragments far into the room. Sound effects can probably be attributed to the rapid release of nitrogen ions from the core particles and to the escape of the nitrogen gas through the broken glass.

DISCUSSION

The main weakness of the witnesses’ reports presented in this study is lack of any information (with one exception – a person reporting red glow

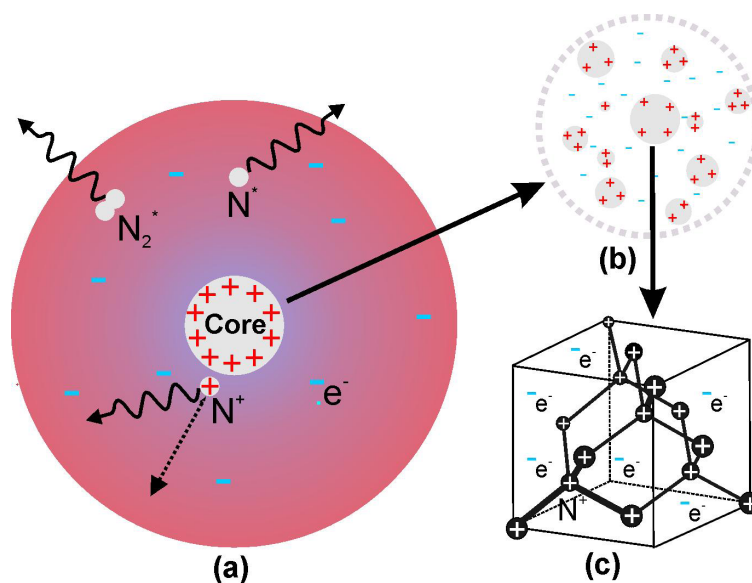


Fig. 7. View of hypothetical internal structure of the ball lightning. (a) Positively-charged core of aggregated nanoparticles, crystallized from nitrogen cations, surrounded by a glowing spherical region where de-excitation of nitrogen: ion, atom and molecule occurs. (b) The core composed of the charged crystalline nanoparticles immersed in a cloud of negative air ions or electrons. (c) Diamond-like structure of the core nanoparticles formed from positive nitrogen ions N^+ bound covalently and glued by electron gas

in windows A) on the object striking the window and confirmation to have a typical BL form. This can be explained by a fast movement of the object outside the room, different directions of view of persons located in the room, many flashes from ordinary lightnings, and probably an elongation [19] or even complete disappearance of the glowing cloud/halo around the fast-moving BL core. It should be emphasized here that in the literature there are reports on window pane destruction attributed to ball lightnings though a BL was not seen [1, 20].

The on-scene inspection of material traces and laboratory analysis deemed it necessary to correct witnesses' reports and propose consistent interpretation of the incident. The crucial arguments were obtained from reconstruction of broken glass panes, which was possible due to the author's immediate arrival at the scene. The analysis of the incident can be compared with efforts made by Keul [21] in the interpretation of traces left by a BL on a laminate floor in Ramstein-Miesenbach (Germany) or by Pudovkin [19] in analyzing the behavior of a BL in Novosibirsk (Russia) and unusual traces left by it on a pine trunk. Unfortunately, a critical and fast analysis of traces is rare in the literature on ball lightnings. Perhaps this is the reason why the literature reports [1, 20] are not consistent in describing the effects of a BL on the surrounding objects, for example on a window glass. Therefore, it is reasonable to mention a recent paper of Bychkov et al. [22], who concentrated on the problem of BL passing through the glass pane of a closed window and applied modern instruments to analyze the traces in the glass. There are reports supporting the view that BL can cross window glass without any damage. However, there are many observations of a bored glass. In some cases, holes in the panes were circular; three of which, investigated by Turner [20] and discussed by Smirnov [3], were of about 5 cm in diameter. It is worth recalling that the hole in the mesh analyzed here has a similar diameter. In most of these cases, the examined holes showed fracture not melting [20]. This inference is in agreement with the type of breaking of the glass from the window A. Similar damages to the analyzed mesh were reported for the fabric investigated by Stenhoff [1, 23], where BL has interrupted without charring the synthetic fabric of a dress, though shrivelled fibers were observed.

Expectation of solid particles inside a BL is not new and has been reported in several theoretical works [3, 15-17]. Nanoparticles of silica were

detected in fireballs generated by microwaves [24] but these fireballs were short lived (ca. 30 ms) to be regarded as real ball lightnings. The internal structure of the core is explained in the literature [15] to be a homogeneous crystalline form created from hydrated ions or it is assumed to be a piece of metal [16], aerogel of silica particles [3] or burning silicon nanoparticles [17]. The novelty of the BL structure proposed here lies in the assumption that solid nanoparticles are composed of covalently-bonded nitrogen ions N^+ . The size of particles was postulated here to be small (nanometers) as limited mainly by a short time of their growth, and is in accordance with the estimates made by Smirnov [25] to be in the range between 1 nm and 10 nm. The observed absence of any residues after the end of a BL may be due to formation of gaseous nitrogen from the main part of the BL mass, though it is possible that some other substances can be attached to the BL by electrostatic forces as impurities.

CONCLUSIONS

During the powerful summer thunderstorm in Rozkopaczew (Poland) in 2001 an interesting incident took place in the form of nearly instantaneous breaking of panes in two windows A and B, located on two perpendicular room walls. General opinion of nearly a dozen eyewitnesses was the incident has been caused by a thunderbolt passing with a great velocity close to them across the room when it entered through the window B and escaped through the window A. This witnesses' opinion was recorded and emitted by a local TV without any substantial changes. Analysis of traces, carried out later by the author on the scene and in the laboratory, exclude this route of a body/lightning because both window panes were broken by external impacts. This incident as well as the one described in the cited article from a local newspaper, mentioned in Introduction, are examples of the importance of quick on-site checking of facts to prevent spreading of misinformation in the scientific literature.

Ball lightning still remains an unsolved problem in physics mainly due to the lack of convincing results of planned observations. Therefore, it is important to have teams of researchers able to follow mass-media or social media and investigate reported BL incidents on the spot as quickly as possible. Samples of objects having contact with the BL should be collected and stored in order to carry out more detailed studies or tests in

laboratories in the future, also by other groups of scientists. Their research may give rise to hypotheses about the structure of BL that can be tested in the laboratory. Analysis of mechanical damages of the glass panes and the windows meshes in this work has led to the hypothesis that the BL core may have the form of an aggregate of solid nanoparticles created from crystallized nitrogen ions N^+ , what can be examined theoretically in future by *ab initio* quantum mechanical computations. Moreover, the model of BL proposed here can be useful in attempts to create and analyze such object in laboratory experiments or with use of triggered lightning. An experiment should be based on breaking the air molecules to atoms, ionizing and pressing them to be in a close contact sufficient for formation of covalent bonds.

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