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Fluorescence caused by ionizing radiation from ball lightning: Observation and quantitative analysis

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ABSTRACT

Ball lightning is a rare phenomenon, typically appearing as a glowing sphere associated with thunderstorms. In 2008 one of the authors witnessed a blue ball-lightning object hover in front of a glass window that appeared to glow yellow. Calibrated quantitative fluorometry measurements of the window show that the glow was probably due to fluorescence caused by ionizing radiation (UV or possibly X rays). Based on the measurements performed, estimates of the total ionizing-radiation power emitted by the object range upward from about 10 W. These are among the most reliable semi-quantitative measurements so far of ionizing-radiation output from a ball-lightning object.

1. Introduction

Ball lightning is a phenomenon whose existence has been known since the pre-scientific era (Stenhoff, 1999), but which has so far eluded both a widely accepted scientific explanation and reproduction in the laboratory, although many theories have been proposed to account for it. Its rarity compared to conventional lightning makes instrumented scientific observation difficult, with the result that most of what we know about it is based on the testimony of eyewitnesses who happen to be present when a ball-lightning event occurs. Rakov and Uman list four features of ball lightning that are common enough in eyewitness reports to be regarded as characteristic (Rakov and Uman, 2003, p. 662): (1) its association with thunderstorms, (2) its light emission, spheroidal shape, typical size range of 10–50 cm, and relatively constant appearance during its lifetime, (3), its occurrence both in open air and enclosed spaces, and (4) the fact that it moves in a way that is inconsistent with a hot gas. Horizontal motions are more common than vertical ones (Rayle, 1966). One of the few cases in which the optical spectrum of a probable ball-lightning object has been reported (Cen et al., 2014) covered only the range 400–1000 nm, so the object's emission at wavelengths below 400 nm, if any, was not determined in that event.

The scarcity of observational data makes it hard to select among the myriad of theories that have been proposed to explain ball lightning. Some of the theories (e g. Shmatov, 2003) imply that ball lightning should emit ionizing radiation (UV and X-rays, in particular), while others (e. g. Abrahamson and Dinniss, 2000) do not. One of the theories that has received much attention in the last two decades is the chemical-combustion theory (Abrahamson and Dinniss, 2000). Abrahamson and Dinniss propose that a lightning strike to soil reduces silica by means of carbon-bearing compounds, leading to the production of elemental silicon which then slowly oxidizes in air. Burning silicon has a black-body-like spectrum with an equivalent radiation temperature in the range of 3000 K (Stephan and Massey, 2008). The emission in the short-wave UV region from such an object would be roughly seven orders of magnitude less than its peak emission in the visible range—in other words, negligible. Spectral lines from silicon and other common soil elements in the Cen observation lend some credence to the Abrahamson-Dinniss theory, although the Cen data are also consistent with other theories of a primarily electrical or plasma nature.

Two leading electrical-plasma theories are a totally-ionized-plasma model (Shmatov, 2003) in which electron-ion recombination is delayed by the high energy of the electrons, and a microwave-soliton model (Wu, 2016), in which a coherent relativistic electron bunch produced by a lightning leader collides with matter to produce an intense electromagnetic pulse, giving rise in turn to a high-intensity standing electromagnetic wave inside a spherical plasma cavity.

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Both of these theories entail that at a minimum, the object is surrounded by a halo of highly ionized air, whose nitrogen molecules can produce lines and bands in the UV range, as well as visible-light emission primarily in the blue region (similar to emissions of high-voltage corona discharges). Also, the Shmatov model predicts substantial amounts of X-ray production due to brehmsstrahlung radiation. At present, the field is perhaps better served by observation of ball lightning and quantitative measurements rather than by development of additional theories, and this paper is a contribution to observations of ball lightning which involve quantitative measurements.

We describe an eyewitness report of a ball-lightning object observed by one of the authors (Krajcik). This report has a feature that, to the best of our knowledge, is unique: the ball-lightning object caused the glass in a window to fluoresce brightly with a color that was different than the color of light emitted by the object. We have subjected the window glass involved in this incident to a calibrated fluorometric study, and show that the glass fluorescence observed during the event implies that significant amounts of ionizing radiation (short-wave UV or possibly X-rays) must have been emitted by the object in order to cause the observed fluorescence. The combination of eyewitness observation and fluorometric analysis makes this the among the most well-documented semi-quantitative measurements of ionizing radiation from a ball-lightning object, although earlier studies (Dmitriev, 1969; Fleming and Aitkin, 1974) provided somewhat ambiguous evidence for such radiation.

2. Material and methods

2.1. Eyewitness report of the incident

The following report contains material transcribed from a recorded interview that one of the authors (Stephan) conducted with the eyewitness (co-author Krajcik) on July 3, 2008. The incident itself took place on June 23, 2008, so the interview was performed only ten days after the incident itself. The eyewitness has a scientific education at the doctoral level and has been professionally employed in research. Following the incident, co-author Martin learned from the eyewitness about the incident. Realizing its significance, he put the eyewitness in contact with Stephan, and conducted preliminary investigations to ascertain if the window fluoresced when exposed to UV light. This preliminary study was followed up with a quantitative calibrated fluorometry measurement when such facilities eventually became available.

On the evening of June 23, 2008, at approximately 8:45 PM (00:45 June 24 GMT), the eyewitness arrived by car in the driveway of her home in southern New York State. An intense thunderstorm was in progress, and this fact is confirmed by data obtained from the National Lightning Detection Network. From 00:41 to 1:13 GMT, the NLDN recorded 24 cloud-to-ground flashes within a radius of 5 km of the eyewitness's home (NLDN, 2008). She stayed inside her vehicle in the driveway to wait for the rain and lightning to decrease. From her vehicle she could see her front porch approximately 6 m away. Her front entry to the house consisted of a transparent and colorless glass outer door (storm door) behind which stood a solid door painted off-white. Here are her words from the transcript of the interview made ten days after the incident: “I just happened to glance over at my porch and I was stunned. I mean, I saw that fiery ball, yellow-flame appearance in my front door… . It was the center of the door, at least twice, two and a half times more area than you'd expect from that small canteloupe-size blue object that I saw.”

An artist's conception of this moment is shown in Fig. 1. What the eyewitness described during the interview, and has consistently described since, was the sight of a glowing blue sphere approximately 14 cm in diameter, suspended a few cm in front of her door. The glass of the door was glowing over a diameter 2–2.5 times that of the blue sphere. The color of the glow from the glass appeared yellow, in contrast to that of the blue sphere.

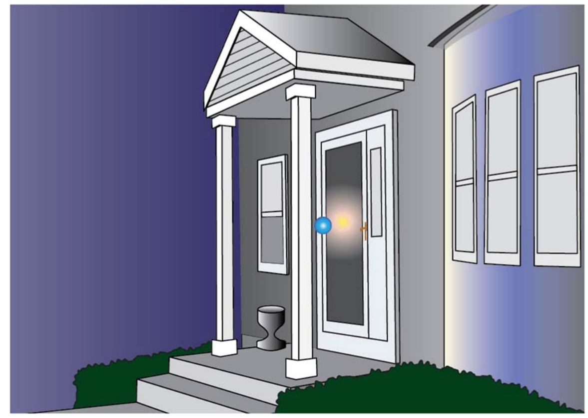

Fig. 1. Artist's conception of eyewitness's initial sighting of ball-lightning object in front of glass window in front door (artwork by P. Stephan).

After this sighting, the eyewitness saw the blue object move rapidly to the right, between her house and her car. The object passed behind a tree at the corner of her house (not shown in Fig. 1) while brightening somewhat, passed to an open space between her house and the next residence, and she eventually lost sight of it.[1] The eyewitness also reported that the electric-utility power had failed before she arrived at home, and was not restored until well after the incident was over.

Summarizing the relevant data from the eyewitness's report, we have the following: (1) during a thunderstorm, a sphere about 14 cm in diameter emitting blue light appeared in front of the glass window of the front door, and subsequently moved in a mostly horizontal direction until the eyewitness lost sight of it; (2) with the sphere a few cm distant from the window, the glass emitted light of a contrasting color over an area larger than that of the sphere's diameter. Although it is possible that the paint on the solid door could have contributed to the observed effect, we have assumed in this paper that all fluorescence was due to the glass and not the solid door.

In what follows, we will combine these data with subsequent measurements and estimates to draw conclusions concerning ionizing radiation emitted from the object.

2.2. Fluorescence of window glass

The same clear window glass was present in the eyewitness's front door from the time of the incident reported above in 2008 until the glass was measured fluorometrically on June 4, 2016. A brief discussion of glass fluorescence and the results of these measurements will now be presented.

Certain types of glass are known to fluoresce in the visible range when subjected to ultraviolet light (Lloyd, 1981) or X-rays (Clark, 1955, p. 78). The fluorescence is generally due to the presence of trace amounts of heavy metals in the glass. For example, a type of glass containing uranium is known as “vaseline glass” because of its yellow-green color, and fluoresces bright green when

[1] The entire transcript of about 6300 words contains more details, omitted here for clarity and space reasons, but the details most relevant to this paper have been included here.