Motion of a BL Discharge Fed by an Atmospheric Maser

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Abstract

The apparently random motion of ball lightning (BL) in open air, in buildings, or in air planes has been interpreted on the basis of the phase differences between the harmonic wave components that make up the soliton. Indeed, the Maser-Soliton Theory of BL predicts the dynamics of each of the harmonic waves in the wave packet that feeds and in fact defines the Langmuir plasma soliton that is observed as BL.

The frequencies in the wave packet are in a narrow window Δf that corresponds in the case of open air BL to the diameter of the area in which the damage caused by the final explosion of the BL is observed. This is usually of the order of Δx=30 m roughly, in rms. The corresponding wave vector interval is Δk=(1/2)(1/30m)=0.017/m in rms. At the same time, k is of the order of 6/m, yielding $k/\Delta k$=360. This pronounced line-narrowing is obtained due to the large gain of the atmospheric maser when it generates the Kapitsa standing wave.

Phase differences between the waves that make up the electromagnetic field that couples with the electrostatic field of the soliton are determined by the frequency dependence of gain and dissipation. They are influenced less by the motion of the air, than by the maser dynamics and by the boundary conditions shaping the electromagnetic field, i.e. the individual photonic wave-packet. The paper presents the equations that determine the phase dynamics and therefore also the observed motion of BL. A similar phase dynamics is expected to be applicable to the special case of UFO motions.

1. Introduction

The Maser-Soliton ball lightning (BL) theory is also known as the Maser-Caviton BL theory (MST) [1]. It was tailored exactly on the observational evidence in 1975, and the various aspects of the MST theory were developed in detail based on the experimental evidence, during the last 3 decades. The maser aspect was developed in an unpublished paper [2] and in later publications [4-9]. The MST theory of the soliton or caviton, of its ignition and of its stationary states, was developed in other papers [10-17]. Papers [8-9] are investigating also details of the interaction between the maser and the caviton.

A BL theory must exactly relate to the known observed properties of BL. Based on over 10,000 cases of BL known, we list the main properties of BL and their MST explanation below.

1) <u>Size, color, duration, absence of buoyancy, horizontal motion segments</u>. The MST explains the absence of buoyancy by the combined effects of:

a) The stability of the ultra-low discharge temperature achievable at atmospheric pressure with the built-in automatic feedback mechanism uniquely provided by the large atmospheric maser, as proven by us recently [17]. This ultra-low discharge temperature corresponds to the normally unstable low-temperature branch that has never been obtained in the laboratory, because no large maser was used so far. Our analytical and numerical investigation has shown that stabilization of parts of the forbidden low-T branch is possible in the maser-like feedback case, even without cold emission, in the stationary regime.

b) The cold (field-) emission of electrons keeps the glow-type discharge going even at temperatures close to the ambient temperature for the E-type (orange) BL, with dynamic stabilization by a rapid sequence of mini-spikes, at the quasi-stationary maser spiking frequency ω_S beyond the quasi-linear regime. This arises because of temporary depletion of the population inversion during a spike. The photon number subsides, yielding excessive recovery, thus a next spike.

c) Therefore, the discharge alternatively extinguishes and is re-ignited again extremely close to its previous location, slightly displaced toward the exact antinode location of the electric field of the Kapitsa standing wave. This cycle repeats itself at the maser spiking frequency ω_S that is in the 100Hz-kHz range and explains the sound emitted by BL. The presence of a large concentration of highly excited atoms, correctly predicted earlier by E. Manykin's group at Kurchatov, (Rydberg matter) facilitates the continuous re-ignition process, being extremely susceptible to field-ionization as mentioned above. As was predicted by Dr. E. Witalis, the presence of the Ramsauer Effect may indeed contribute considerably to the maintenance of low ohmic dissipation and low temperatures, very close to the ambient in the case of E-type (orange) BL which is mainly of capacitive nature. In the case of H-type (white) BL, the discharge is an induction discharge with larger electrical currents, and higher temperature, that is still stabilized dynamically by the continuous extinction and re-ignition. This process will literally pin the discharge at the magnetic (H) antinode, even if there is a remaining buoyancy force. We call this pinning "dynamical stabilization at the maser spiking frequency". The terms "E" and "H" are from G.I. Babat [18], who also noticed the colors orange and white. We associate them with the well known two BL modes, and claim that this explains both the color and the observed existence of the two BL modes.

d) Pinning at the exact antinode of the Kapitsa standing wave also explains the motion of BL preferentially in horizontal direction, by segments, each of them located in a Kapitsa antinode. For instance, a chimney represents a dielectric wave-guide. The modes propagating with a maximum on the central axis explain the BL movement along the central line without hitting the walls of the chimney. The fields do not end at the surface of the dielectric guide, but extend into the masonry. This extension explains why BL can occasionally penetrate some walls, just as it will cross window panes.

e) Occasionally, there is a field maximum at the surface of a metallic object, conductor, or metallic wall. This is known to often cause attachment of the VHF discharge in the laboratory. Our dynamic pinning to the maximum mechanism is much stronger, and will also lead to occasional attachment of BL to metallic objects, conductors, or metallic walls.

f) What causes the BL motion? According to the MST, it is the time dependence of the phase differences between the component waves that form the soliton. This explanation was given by one of us (PHH)at the 5th ISBL in Tsugawa, Japan, and at the meetings of the MST-BL project at Kurchatow (1992-1999). Indeed, all of the previous letters a-f above are based on the exact identity between the photons emitted in stimulated emission and the photons that have caused the stimulated emission of the maser in the first place. Each photon is described by a wave-packet and has a large spatial extension, several orders of magnitude larger than its central wavelength. It consists of a superposition of waves that creates a main maximum at the location of the BL, but may also have many other maxima, separated by distances of many central wavelengths. Phase changes in the component waves in the packet, will lead to a displacement of the maximum, consistent with the boundary conditions satisfied by each of the component waves by themselves. This means, e.g., if there is a node at the surface of the earth, each of the component waves will have a node there, and an antinode at $\lambda/4$, $3\lambda/4$, $5\lambda/4$, … etc., above. Therefore, the motion of the maximum defining the soliton will occur preferentially in one of these horizontal planes in the close vicinity of the earth. Farther away from the earth, because of their different wavelength, the maxima of the component waves will no longer coincide, and therefore, the preference for horizontal motion will fade. No other theory can explain a-f above.

2) Passage through closed windows, about 38% damage probability on the window, occasional microwave heating of close-by conducting objects;

3) Correlation with thunderstorms, tendency toward larger explosive demise energies in free space or enclosures strongly coupled with the outside world;

4) Very low power and demise energy inside well-screened enclosures such as submarines and aircraft;

5) Electrostatic ponderomotive force character of large-energy explosive damages, often without ohmic heating or burns;

6) Frustration of Atmospheric Electricity scientists by BL absence on high peaks used for lightning studies;

7) Difficulty of obtaining BL in the lab at atmospheric pressure;

8) Approach of lower-temperature BL-like atmospheric-pressure discharges by feedback in the laboratory;

9) Connection with earthquakes, UFOs and tornadoes, etc.

2. Phase Differences

Consider the quasi-stationary state of ball lightning in open air, on flat terrain. In general, the occupation of the energy levels that are subject to possible population inversion due to a sudden, large, but short electric field pulse caused, e.g., by lightning, will not be perfectly uniform. As seen from the location of the BL, the population inversion may be slightly stronger in the cubic km on one side (#1) of the BL, than in the similar volume on the other side (#2) of the BL. Considering the direction of the gradient **g** of the population inversion in the region containing the BL, the side #1 is that, to which the small vector of the gradient points. This definition is applicable also in the absence of a population inversion. In that case, the gradient **g** points to where the absorption coefficient is lower.

In our Maser-Soliton theory [1]-[6], [8], [15], open air BL is a nonlinear (solitonic) system of plasma and field, fed by a giant atmospheric maser of several cubic km, usually caused by a lightning flash over flat terrain. The maser causes a standing electromagnetic wave in the space with population inversion. The solitonic HF discharge is initially ignited in one of the antinodes of this standing wave by a mechanism of resonance as was described in an earlier paper [11]. It then continues as a rapid sequence of extinctions and re-ignitions in the same antinodal place, with a repetition frequency close to the natural spiking frequency of the maser.

In particular, the waves originating in region #1 with **k** parallel to **g**, will be superposed on those coming from region #2, forming a standing wave **E**

$$\mathbf{E} = \mathbf{E}_o \exp i[\mathbf{k}\cdot\mathbf{r}-(\omega+s)t] + \mathbf{E}_o \exp i[-\mathbf{k}\cdot\mathbf{r}-(\omega-s)t]. \qquad (1)$$

Here we neglect the slight difference in the amplitudes $\mathbf{E}_o$, and focus instead on the phases. We have denoted by ω the average frequency of waves generated in the maser volume. As is known, this frequency is slightly lower due to damping in the absence of a population inversion. When population inversion prevails, causing "negative damping", it is higher. This will be proven in Sec. 3 below by calculating the part of the phase velocity that is proportional to the population inversion. Assuming for simplicity the BL to be in the middle of the region occupied by the standing wave, in Eq. (1) we have denoted by s the small deviation of the frequency ω+s of the waves in the #1 region from its average over both regions, ω. Then -s is a good approximation for the deviation from ω that is noticed in the #2 region.. We can define the component parallel to k of a vector v, such that

$$s = \mathbf{k}\cdot\mathbf{v}; \text{or} \;\; v_k = s/k. \qquad (2)$$

Then, the elementary standing wave becomes

$$\mathbf{E} = \mathbf{E}_o \exp i[\mathbf{k}\cdot(\mathbf{r} - \mathbf{v}\, t) - \omega t] + \mathbf{E}_o \exp i[-\mathbf{k}\cdot(\mathbf{r} - \mathbf{v}\, t) - \omega t] = 2\mathbf{E}_o\{\cos[\mathbf{k}\cdot(\mathbf{r} - \mathbf{v}\, t)]\}\exp i\omega t. \qquad (3)$$

This is a standing wave that is moving with a velocity v_k given by Eq. (2). The component of **v** perpendicular to **k** is left arbitrary. It can be determined by other factors, such as the direction of a prevailing wind, and by the boundary conditions affecting the standing wave at the surface of the earth and at the limit of the space occupied by the cloud and by the polarization catastrophe, if present.

Choosing the origin of the coordinate system at the location of the BL, for s=0 we can express the total electromagnetic field of the standing wave, including the BL, in terms of a cosine- Fourier integral, or packet of standing waves

$$E_{tot} = \int E(\mathbf{k}) \cos \mathbf{k}\cdot\mathbf{r} \; d^3x \qquad (4)$$

Centered on the origin. This is possible due to the assumed symmetry. With a small s different from zero, considering Eq. (2), this will become

$$E_{tot} = \int E(\mathbf{k}) \cos[\mathbf{k}\cdot(\mathbf{r} - \mathbf{v}t)] d^3x, \qquad (5)$$

and the BL will start to move with velocity **v**, as we have shown, in the opposite direction of the gradient of the population of levels, defined above.

In general, therefore, we conclude that BL tends to move away from the region of larger population inversion, or towards the region with larger absorption coefficient. This may explain the seemingly erratic motion of BL, often along horizontal antinodal planes. It may also explain why open air BL is often seen descending from the clouds, in which 80% of the streak lightning activity is known to take place. Indeed, the population inversion is likely to be larger above.

For the motion of BL close to ground, the boundary conditions that determine the antinodal areas must be taken into account. This is true also for BL inside closed spaces, such as inside airplanes.

In general, in airplanes, the boundary conditions restrict the BL to the centerline in the passenger room. There is a general motion of the air from front towards the back of the plane. If there is a population inversion in that air, it will decay while the air slowly drifts to the end of the plane. Therefore, BL will move toward the back, away from the higher population inversion, with a speed that is likely to exceed the speed of the airflow.

3. Molecular Formulation

The preceding formulation can be expressed also more explicitly in terms of the dielectric function and quantum mechanical matrix elements, in order to prove . The permitivity is

$$\varepsilon = \varepsilon_o[1 + \chi(\omega)] = \varepsilon_o[1 + \chi'(\omega) + i\chi''(\omega)] \quad (6)$$

The susceptibility introduced by a population inversion N_n-N_m per unit volume on a molecular transition of frequency ω_{mn} and damping γ is

$$\chi(\omega) = -3i[e^2F_{nm}(N_n-N_m)]/\{m\varepsilon_o\omega_{mn}[\gamma_{rad} + 2i(\omega-\omega_{mn})]\}, \quad (7)$$

where $\gamma_{rad} = 1/\tau_{rad}$ must be replaced by the total linewidth $\Delta\omega_{mn}$ to include all forms of broadening. The oscillator strength F_{nm} is related to the molecular quantum mechanical matrix element r_{nm} and to the real molecular damping rate τ_{mn}

$$F_{mn} = 4\pi m\omega_{mn}r_{mn}^2/3h = \tau_{rad}/\tau_{mn} . \quad (8)$$

The phase velocity is $v=c/n=c/\varepsilon^{1/2}$. Therefore, for $\chi<<1$ it can be written as

$$v = c/(1+\chi'/2+i\chi''/2) \approx c(1-\chi'/2-i\chi''/2) \quad (9)$$

The small differences present in ω=kv is given by the term χ'. Thus,

$$s \approx -\chi'kc/2 = -3kc[F_{nm}e^2(N_n-N_m)(\omega-\omega_{mn})]/ \{m\varepsilon_o\omega_{mn}[(\Delta\omega_{mn})^2 + 4(\omega-\omega_{mn})^2]\} \quad (10)$$

This is proportional to (N_n-N_m). It proves the assertion made in Sec. (2) above, that the phase velocity contains a small term proportional to the population difference between the levels involved in the maser effect.

4. Conclusions

An important cause of BL motion is the phase difference that can occur between the components of the standing wave feeding the BL. This has its cause in turn in small variations of the level population difference, or population inversion.

Wind can add a certain velocity component to BL when the whole maser volume is moved, but this is in general smaller than the velocity caused by phase differences in the two parts of the standing wave. Finally, electromagnetic boundary conditions place restrictions on the BL motion, and also generate a preference of horizontal motion along antinodal planes.

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