Ball Reactor: Current Status and Prospects

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Abstract: By experimenting with a variety of targets, gases, and pressures, the objective is to create an analog to natural ball lightning (BL), discover optimal conditions more favorable than atmospheric, and investigate the anomaly. Twenty symmetrically placed helical antennas inside a 56 cm (22 inch) diameter aluminum sphere deliver up to 20 KW of 2.45 GHz circularly polarized microwaves for about 0.1 second. Various devices and arrangements provide a seed plasma (a miniature plasma jet, exploding central targets, etc.) for the microwaves to interact with and heat. If the plasmoid continues for even a short time after the externally applied microwaves end, the experiment is a success, as cooling and recombination for a normal plasmoid should be supersonic. As natural BL shows strong evidence for producing microwaves, and must be sustained by an unknown exothermic reaction, an optimized ball reactor could be an energy source of high energy density and direct conversion without thermal cycles or appreciable pollution.

Note on terminology: a *plasmoid* is a self-contained bundle of electromagnetic and material energy, and is frequently used as a synonym for a spheromak. In this paper, "plasmoid" describes the organized and contained plasma object. Engineering realities in the US frequently require inches, but metric units predominate whenever possible.

I. INTRODUCTION

To initiate research, I proposed an investigation of Spherical Microwave Confinement (SMC), a configuration that is a novel type of plasma trap. This relies on a new combination of known physics with the potential for high temperature long-term confinement in the low collision regime where magnetic fields strongly influence particle behavior. This requires relatively high vacuum and, although the magnet is not strong by fusion standards, a very complex and somewhat costly coil. In the original proposal I noted that it might be possible to investigate BL in the same apparatus at higher pressures and without the magnet. (Since I expended great energy in the theoretical basis for SMC and it remains potentially of interest for research someday, I will include this in my thesis, possibly as an appendix.)

Since initiating construction in August, 2006, it became evident that the technical and economic challenges of a full SMC experiment are beyond the capacity of my solo, unfunded effort. By simply not building the magnet and using the bulk of the capacitors only for the magnetrons instead of sharing them with the magnet, the same equipment is now suited for BL experiments, with a few additions of novel gear.

Recent research shows that SMC can be modified with the addition of biasing ring electrodes at the base of each antenna to make a novel form of Inertial Electrostatic Confinement without an internal grid. The results of this research and future experiments will be the subject of a separate paper. It is unlikely that these electrodes will factor into BL experiments as the fill pressure required for them to have an effect is well below the probable BL range (1- 100 mTorr).

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For the moment, I am calling the device a ball reactor. This is because of the motivation coming from natural ball lightning. However the reactor does not creating “lightning”, and my emphasis is on eventually creating a genuine reactor. There is, after all, some unknown reaction that sustains BL and generates the anomalous microwaves detailed below, which could be harvested directly by rectification. The goal is to find optimal conditions for the plasmoid, and thus be able to study the phenomenon for the first time and design an ideal power reactor.

As of this writing (early October 2007), the basic reactor is finished and has undergone preliminary trial runs showing that it does indeed function, although not producing a well-defined central plasmoid or anything that lasts after the microwaves stop. A section below gives the latest results. The power is such that small mistakes and even normal operation will destroy insufficiently sturdy components, so much of the current work consists of replacement and redesign of what breaks, burns, or blows up. As of this writing the ball reactor can operate repeatedly without breakdowns at 3 torr, but there are poorly understood problems at atmospheric pressure. Pressures higher than atmospheric should also be investigated but will require substantial changes to the present equipment. My website includes this write-up in its latest form, along with photos and videos from inside the reactor during operation.

II. EXISTING ART OF BALL LIGHTNING

In my thesis I will detail current theories and purported laboratory creations of BL, none of which are valid. Here, I give a brief summary.

There are several websites[1,2] and some journal articles[3] describing fireballs in 2.45 GHz microwave chambers (usually ovens) formed with aerosols. These are frequently described as ball lightning (BL), although there are many differences between natural BL and the fireballs. The most obvious is that nature does not require an external power source or reflective chamber. All the fireballs extinguish within microseconds of turning off the microwaves, and some only last milliseconds even with continuous external power. Also, the fireballs are buoyant, while BL does not typically float up. Recently there are reports of underwater discharges forming non-microwave-related fireballs, which have anomalous durations of up to half a second instead of the anticipated millisecond. However these are buoyant in air, unlike BL, and do not have the same shape, power density, or other characteristics usually found in natural BL. Thus there is progress and demonstrated anomaly, but not yet synthesis.

It is impossible to design a BL reactor directly from theory as nothing is known of BL physics—not its confinement mechanism, temperature, formation, or even its constituents, and certainly not optimal conditions. There is no reason to suppose that atmospheric conditions are best for BL. All proposed theories are fatally flawed when matched to the full range of reliable observations. It is known through damage reports that high-energy BL, and probably all BL, broadcasts microwaves at wavelengths roughly corresponding to its size. High-energy BL produces energy at densities far beyond the range of chemical reactions or thermal energy storage, although no known nuclear reactions seem possible.[4] (Only one observation recorded radiation effects, which devastated a village in Venezuela in the ‘30s.)

There are many unsolved mysteries with BL. One is that neutrals are confined as well as charged particles. This is evident from several factors repeated in observations;

BL doesn't cool, at least over several seconds, but if hot neutral gas could convect out it would do so in less than a second. BL can fizzle, but also typically pops or even explodes violently on its demise, implying internal neutral pressure. The ionized component is parts per million, hence the partial pressure of charged particles is insufficient to explode at all. Also, BL doesn't rise, so it's as dense as the surrounding air, despite its temperature—requiring internal pressures of the order of 15 atmospheres if the temperature is several thousand K, as the color suggests. Even if there were a way to confine the tiny fraction of charged particles with electric or magnetic fields, there is no known way to confine neutral gas molecules or atoms except by solid or liquid surfaces.

Consider this: the only known confinement mechanisms for non-transient plasmas require external fixed magnets, as the thermal plasma pressure transfers to the magnet mounts equal and opposite forces. Since that is not applicable here, there is a basic Newtonian problem of force balancing in lieu of tension, which is only possible in solids. In addition, all magnetic confinement requires that the collision rate be lower than the gyrofrequency, so that the collisions don't bounce the particles out of the field lines. Otherwise there is little or no difference in diffusion rates parallel or across field lines, as is the case in atmospheric cool plasmas like flames. So even if there are magnetic fields they would make no more difference than they do to a candle.

There are also BL and BL-like reports over fault zones during seismic events, although there is a much wider range of phenomena than with storm-related BL. This includes long-lasting lights of odd shape, aurora-like events, and diffuse forms. This may be why Japan BL sightings are unrelated to storms at least 80% of the time, while in the rest of the world something like 90% of reports include storms in some way.

The inevitable conclusion from BL observations is that there must be a power source that sustains the plasmoid. The upper bound for energy density is in the range of 10^9 J m^{-3}; the power output is in the form of microwaves and, sometimes, an explosive end. The goal for a BL-based reactor would not be necessarily to recreate natural BL, but rather to host the mysterious reaction that sustains BL. This would make an ideal power reactor with no radioactivity, direct energy conversion from the microwave outputs, light weight, and (evidently) abundant fuel. With no understanding of why some BL explodes and some does not, there is a hazard that some configurations may lead to significant detonations.

III. OBSERVATIONS OF NATURAL BL

Given the complete lack of theory, the only guidelines for design of a reactor are from the thousands of BL sightings that have been recorded in sufficient detail. My thesis will review those most of interest, especially concerning high-energy BL, variations in shape and color, how it forms, different environments, evidence for aerosols, damage reports (especially those indicating microwaves as the only possible means), and smell. The conventional approach has been to ignore or modify the observations to make some physical theory plausible. My approach is to assume that multiple observations are valid regardless of how impossible they may appear, and if that means not being able to apply a known physical theory, so be it.

My thesis will give an overview of the important *conclusions* from observations and statistical breakdowns of the records, as other compilations exist for references to the original sightings. The vast majority of observers do not record their experiences, and I have met several people who have had personal encounters with BL but who have never told any investigator. As interest grows and the internet informs people of the importance of recording and reporting, the available literature is expanding and is available on-line on many sites. Books and publications are not the best sources of information on BL even with the lower reliability of the electronic medium. This is because there has been no theoretical work of any validity, so the important material to access are the raw data from the field, properly organized.

IV. TEST REACTOR DESIGN

The first ball reactor, as for any prototype, needs to be modular, easily modified, and highly provisional. My fundamental setup is as follows; a rack holds power supplies, two capacitor banks, and a control panel. This connects to two sets of shelves on casters that hold the two hemispheres, magnetrons, transformers, pump, camera, and all the gear attached to the sphere. One antenna switches to a rectifying circuit so that any residual microwave energy can be detected. As yet, until there is indication of an anomaly, the reactor is not equipped to harvest excess energy, but such capability is possible to add to the current reactor.

A. Aluminum Sphere

The pressure chamber is an aluminum sphere. Spheres and hemispheres in the U.S. are available in stock sizes graduated in inches; custom sizes require substantial cost for tooling. The nearest size to the 21.5 inch spherical resonance node for 2.45 GHz is 22 inches (although as noted above, resonance is not expected after the plasmoid forms under external microwave power). This diameter allows ample space for one-wavelength-long antennas. For strength and to accommodate extra holes, fittings, and changes expected in a prototype, the first sphere is spun from plate 0.86 cm (3/8 nominal) thick, with the resulting wall thickness only slightly less than that. The two hemispheres are side-by-side with a vertical seal; each mount on strong steel shelving on large casters. Thus, the entire apparatus divides into two parts, allowing full access to the inside of the sphere. The hemispheres can be separated from each other and remain rigidly fixed to all attachments, such as pumps, power supplies, cables, grounds, etc. with minimal disruption to connections, and no lifting. Each half of the reactor measures 18” by 36” and is 64” tall, which will fit through standard doors. The aluminum inner surface is sandblasted for better vacuum characteristics, but not plated with copper or silver as the plasma will absorb microwaves efficiently leading to low Q of no more than 50, and probably much lower. Each of the 20 coax cables will provide grounding points for the sphere through the coax sheaths. To function as a ground plane for the antennas, the pressure sphere needs many grounding points; currently this is not yet incorporated onto the reactor.

At each pole, a 1 ¼ inch nom. schedule 40 aluminum pipe welds onto the pressure chamber. This allows ample room for probes as well as openings for gas entrance and exit ports, while keeping the spherical shape as uninterrupted as possible.

In a few weeks I will replace the current and very approximate equatorial seal with a flange with an o-ring. In addition I will replace the antenna feed-throughs which will allow operation down to about 1 mTorr, as well as above 1 atm. This is a substantial upgrade, as the current design cannot handle positive internal pressure, nor is it secure enough to use hazardous gases such as hydrogen sulfide.

There is some concern about the homemade nature of the coax connector outside the sphere. These usually are right-angle connectors and slide over the bare 10 gauge antenna wire; as a result there will be some reflections. Without a magnet fitting over the hemispheres, the connector could be radial instead of right-angle and thus have fewer reflection problems. However the angles do simplify the magnetron mounting and coax configuration. Once again, twenty right-angle commercial connectors in addition to twenty through-wall connectors capable of carrying 1000 W at 2.45 GHz would be a substantial expense.

A residual effect from SMC design is a slot cut in each hemisphere from the equator to very near the pole to reduce eddy currents from the pulsed magnetic field. The slot is filled with epoxy resin. As there is no metal joining the equator end, the hemispheres are considerably weakened by this slot, which would be greatly strengthened by a welded flange. It is completely unknown if this slot and the interruption of eddy currents would help in a ball reactor. The inner baffles also are insulated in such a way as to stop eddy currents circulating all the way around the hemispheres in directions parallel to the equator. Current plans are to weld this slot shut when the flanges are installed.

There are two circular polycarbonate windows of 5 cm diameter, each with metal grate inside taken from the window of a microwave oven. In addition they have plastic sheet on the outside that reduces RF radiation by 20 dB. One port is for the video camera and the other currently is for visual use. As with most fittings these ports are hand-made.

B. Antennas

The antennas are arrayed symmetrically inside, pointing inwards, tapered radially to present the smallest possible shadow on the ground sphere. The proportions of the coil depend on the frequency, number of turns, radius of the outer sphere, and the radiation directionality and gain desired.[5] The circumference of the helix at the midpoint of the coil should be one wavelength. The coil length needs to be at least one wavelength long for sufficient gain. One-wavelength antennas will have 4 ½ turns evenly spaced. The thickness of the copper wire is 10 gauge (0.259 cm), which is thick enough for good structural integrity and below the 5% of wavelength limit. The wire is coated with ITC 296A ceramic[6], which does not require baking. This ceramic prevents direct interaction with the plasma. More advanced antennas will be wound with Kovar, Invar, or other low-expansion alloys, and have ceramic or glass baked onto the surface. This will help when using corrosive gases like hydrogen sulfide, which would react with copper wire. The base of the antenna, just inside of where it meets the wall on the inside, is coated with rubber insulation; it must be flexible to allow adjustment, and insulated to avoid arcing.

The distribution of the antennas is icosahedral, at the centers of each of the twenty triangular faces. The icosahedral symmetry allows easy placement of radial baffles along the edges of the twenty triangular faces. These are aluminum flashing and will reach inwards as far as the antenna tips, which is about halfway to the center. The baffles prevent interference that would cause unwelcome cancellations and would cause crosstalk and possibly arcing among the twenty magnetrons.

Each antenna has its own oven magnetron. The magnetrons feed into 75 Ohm cables which then lead to what would be 150 ohm antennas in free space. However the baffles make the impedance about 80 ohms along the length of the antennas. There will be reflections due to the impedance mismatch with the space inside the baffles and the plasmoid itself; baluns to match impedances will probably be impractical and not required due to the high frequency and efficient power absorption of the plasma. Operation without breakdown or any plasmoid might damage the magnetrons. The very small duty cycle should alleviate any heating problems. Future designs aiming at higher efficiency will include more careful impedance matching. Due to budget constraints and the customized requirements for some components, several critical parts of the microwave circuit are hand-made, including the transition from the magnetron stub antenna to coax, and from coax through the wall to the antenna. This will result in some reflections as well as some gas leakage in the through-wall seal that would be avoided in a costlier setup.

It is unclear whether the handedness of the antennas makes a difference. As a result of SMC design, the polar antennas (five surrounding the polar pipes on each hemisphere) have one direction and the equatorial antennas (five on each hemisphere near the flange) have the other. This might aid in preventing cancellation at the center; in SMC, the direction is critical in the way electrons orbit around the imposed magnetic field, as will be described in detail in my thesis. There is unlikely to be a resonant condition in the ball reactor with the externally generated microwaves; however since BL emits microwaves, there may be a resonance after the magnetrons cut off. Having antennas of both right and left handedness could be of advantage in receiving microwaves generated by the plasmoid.

The antennas produce an end-fire radiation pattern; the circumference, number of turns, and turn spacing determine how tightly focused the energy is. For reactors using one magnetron and dividing its power, antennas of similar helicity will have a phase relationship to ensure as nearly a common direction for **E** at the plasmoid in polar and equatorial regions respectively as possible (given a common handedness among polar, and opposite to that in equatorial). However the first reactor has 20 magnetrons and no specific fixed phase between antennas.

The half-power beamwidth for a helical antenna is approximately

$$\text{HPBW} = 52 / [C_\lambda (N\, S_\lambda)^{1/2}] \quad \text{in degrees}$$

with N = number of turns, C_λ = circumference in wavelengths, and S_λ = turn spacing in wavelengths. This is for cylindrical and not conical antennas. For the proposed reactor, HPBW will be about 50^o, measured from the middle of the antenna.

All the antennas are center-feed with a short tangential stub from the center wire to the beginning of the coil. This is a very convenient geometry compared to edge-feed with no appreciable difference in performance.

In the current arrangement, one antenna has a coaxial relay just outside the sphere, which normally connects the antenna to the magnetron as with all the other antennas. (I have three more relays, ex-Soviet military from the Ukraine, that could do the same if need arises; ultimately each antenna may have such a switch, triggered when the microwave input stops. The connections must be laboriously hand-fitted.) When the relay is tripped, the antenna disconnects from the magnetron and connects to another coax cable leading to a Schottky rectifier and an inductor in series, which allows measurement of a DC voltage. If there is any voltage at all after the magnetrons cut off, then the experiment is a success. For power production, the series inductor would be replaced with a resistor parallel to the load to form a low-pass filter, most likely ultracapacitors storing the pulse and feeding current at lower voltages into batteries. Ultimately, if this actually works, these batteries would run the power supplies to the magnetron and sparker capacitor banks and complete the cycle. This will require rather sophisticated power circuitry that is currently beyond the scope of the experiment and would require some assistance and funding to develop. Once this is done, a true test of the ball reactor concept would be to isolate the reactor and produce power beyond the initial battery charge in a way that cannot be fraudulent, such as on a boat or trailer. As the claim is so extraordinary, before such a test, any positive results must be considered provisional. The present experiment is not sophisticated and there is more danger of a false negative result than a false positive.

D. Magnetrons

I use 20 oven magnetrons rated at 1000 W arranged in four banks of five each. Each hemisphere has a bank above and below.

The magnetron power supply is in two parts. The cathode filaments require 3 VAC at 10 A, from the low voltage secondaries of oven transformers. In practice I removed the HV secondaries from four oven transformers and wound four extra 3 VAC secondaries in their places, so that each bank of five magnetrons has one transformer powering the filaments. For complete control of the voltage, the four transformers run on power from a variac plugged into 110 VAC. On top of this filament power comes a 5800 V (initial) pulse from a capacitor bank. This voltage corresponds to the peak voltage from the pulsed, rectified power the magnetrons receive in ovens. The magnetrons function until the voltage is about 4000 V. The peak power should be about 20 kW, although the losses from reflections from the magnetrons to the reactor interior are unknown at present. The impedance of the chamber itself will fluctuate enormously as the plasmoid forms and dissipates, so trying to tune the input to match under all conditions is pointless. However if the plasmoid generates anomalous microwaves in the manner of natural BL, the resonance may be self-defined and stable. There is danger of reflections and cross-talk damaging the magnetrons through internal arcing; the hope is that the pulse is short enough and the baffles effective enough to keep this to a minimum if not eliminated entirely. As the pulse is less than 0.15 second, damage is probably not going to happen, but there could be interference with production of microwaves.

Air cooling for the magnetrons will suffice due to low duty cycles ($< 10^{-3}$) and may even be extraneous. Most of the heat will be from the filaments operating at 30 W for several seconds before and after the pulses. The filaments could operate for much shorter times, and would in a power reactor, but this is a complication of control that is not required now. The magnetrons are connected in four groups of five, and each group has forced air cooling from a squirrel cage fan. There is little power loss in the helical antennas and they will not require cooling in the test reactor even though the ceramic coating and vacuum environment will make heat transfer difficult. Reactors operating at higher powers will require active antenna cooling, probably with an appropriate oil with low-expansion alloy tubing for the conductor and baked-on ceramic insulation.

E. Sparker

For initial plasma formation and introduction of experimental aerosols (vaporized organic powders), I use a miniature coaxial plasma jet at the end of ¼ inch outer diameter stainless tubing about 65 cm long. The inner electrode is a 5 inch long, 1/16 inch diameter tungsten welding rod, with the cavity at the last half inch, the rest sealed with a low-temperature glass frit backed up with porcelain. The current pulse (negative from the capacitors) goes along the central tungsten electrode, through the target material placed in the end (organic powder with carbon dust), and back through the stainless tube to ground outside the sphere. It runs in the south polar pipe and just past the inner baffles, carefully insulated from all metal contact, since any path to ground besides the intended one will erode a good deal of metal by intense sparking. The tube can be removed and reloaded with new powder between discharges with minimal gas leakage (a few torr starting from 3 torr) by sliding it past a greased o-ring seal and then closing a ball valve. It has a capacitor bank pulsed power supply of 417 mF and no more than 2000 V. Higher voltages decrease the effectiveness of the sparker, require larger and inconvenient dimensions. For the initial tests, the sparker and magnetron capacitor banks fired simultaneously, but the sparker burst was over before the microwave power started any breakdowns. I am now using an inductor made by connecting the HV secondaries of three oven transformers in parallel, then leading to a potentiometer for tuning the time constant. This gradually increases the power to the sparker relay until it triggers, allowing good control of the delay between the magnetron and sparker capacitor bank discharges.

This sparker design is in flux as the tungsten electrode tends to warp after repeated use, and cannot be bent back to a central position without breaking. Alternatives to the sparker are discussed below under Ball Reactor Fuel.

F. Other details

The baffles would work better if they were electrically connected all along their outer edges to the reactor wall, as they are to each other on most of the vertices. However, this is not yet practical, especially in this prototype, since great flexibility is necessary and access to the entire inside is required from time to time. Now they are bolted onto small aluminum angles that are glued to the wall with conducting silver epoxy, as welding or soldering them was not practical. The epoxy is barely strong enough and has broken several times, since the baffles are easy to bump and must withstand some abuse.

Internal lighting is a necessity for several reasons. The video camera must have something to focus on before each pulse, and it is necessary to verify that it’s operational. To provide comprehensive lighting, I mounted five small incandescent light bulbs on the baffles of the north hemisphere and the switch on the control panel. These blew out during the first atmospheric test, although they survived the initial 3 torr test; I replaced them with a small bank of 12 V LED lights outside a window. The sparker provides a very bright flash and the breakdown from microwave power is also quite bright, allowing short shutter times for the video camera.

There is a limited range of appropriate wavelengths for the ball reactor in this configuration. Power transmission favors longer wavelengths, while reasonable reactor size and the extreme savings of a factor of about a thousand by using 2.45 GHz are major considerations as well. With the upper frequency limit of about 5 or 6 GHz for the antennas and the power limits of semi-rigid coaxial cables, the practical range for frequency in this type of reactor is from 2 to 5 GHz.

The most economical microwave sources, by several orders of magnitude, are 2.45 GHz magnetrons, easily available in 1000 W rated power appropriate for the reactor. As a result this is the only practical option for the test reactor. Dividing power from one magnetron to the 20 antennas is prohibitively expensive and results in relatively low power levels if using a household oven magnetron. 20 oven magnetrons each rated at 1000 W are far cheaper. However this does lead to potential problems and negates control of phases of the individual antennas.

The polar pipes allow for easy access to the interior and include mountings for a fiber optic borescope probe with a video camera, a fiberoptic lead for a spectrograph, instrumentation for pressure, temperature, ionizing and microwave radiation, and a plasma probe. My initial attempt at fiber optics failed due to distortions in the cable caused by the atmospheric pressure against the vacuum. Currently the video camera works through one of two small windows. The vacuum pump is on the north hemisphere and attaches to the north polar pipe, while the gas inlet is on the south polar pipe.

Due to the original SMC configuration, it is possible to add two hemispherical magnet coils outside the aluminum sphere, but that is not currently feasible.

Once an anomaly is evident, it can be measured in part by switching one of the antennas with a coax relay from its initial connection to the magnetron to a rectifying circuit using Schottky rectifiers and a series inductor. This will allow measurement of the resulting voltage and hence evidence for microwaves produced by the plasmoid. Once these are is measured, replacing the inductor with a parallel capacitor (a low pass filter) and putting such a relay on all twenty antennas will allow actual energy conversion, storage in ultracapacitors, and then through some power management circuits, battery charging. Ultimately the dream is to complete the cycle by powering the capacitor banks with this energy and have excess left over. This is well beyond the capability of the current research effort but would be logical next steps.

The major deficiency of the current reactor is a lack of adequate measurement equipment. Plasma diagnosis tends to be expensive and complex. In the near future I will equip a computer for data acquisition and increase the number of parameters measured.

The main variations will be aerosol composition, various gases and pressures, timing between sparker and magnetron pulses, and power supplied. Other variations require quite a bit of hardware adjustment and are mostly unpredictable, so the design must be modular and variable as well as economical. So far the main deficits are in instrumentation, as measurement tends to be expensive. If there is a plasmoid that lasts beyond the microwave input, and especially if there is anomalous power produced, that much can be detected in the present configuration with just a little more additional gear. With that much demonstrated, it then would be appropriate to scale up the research for more sophisticated plasma diagnosis. If there is no anomalous plasmoid then there won't be much to measure.

V. BALL REACTOR FUEL

My experiments will include projecting a plasma formed from organic material shot from the sparker into various gases, with hydrogen sulfide a prime candidate. H_2S would probably be formed by loading the sparker with some fraction of sulfur and discharging it into hydrogen gas. This is because soot and aerosol are evident in many BL sightings, and from reports of acrid odor, typically of ozone or rotten eggs. The only available solids in air that would make soot are living things. Thus, I will take the novel approach of using ground-up insects and other similar material in the miniature coaxial sparker mentioned above. This deposits glowing sparks explosively to form targets for the microwave pulse.

One disadvantage of the sparker is that the resulting blast has no coherence and consists of thousands of individual incandescent particles that fill a large proportion of the reactor volume. It may be that the desired plasmoid forms better with a more centralized single initial target. If this is the case then positioning such a target can be somewhat problematic. A sparker tube cannot be expected to penetrate close to the center as it is far too disruptive, and currently is limited to firing in from no more than halfway to the center. If the target must be vaporized to the point of being a seed plasma, then it could be suspended by wires thin enough to not interfere with the reaction but thick enough to not explode under the current pulse. This would be acceptable in a research reactor but is clearly not feasible for any power reactor, as shown in plans for fusion reactors. The pellet might be intrinsically explosive and detonate either from the microwave pulse or an electrical trigger. For instance, a very fine wire coiled and coated with black powder or other thermally sensitive explosive could be at the center of a pellet; when the wire heats from the microwaves, the black powder would explode and could in turn detonate a coating of high explosive mixed with any test material. Alternatively a pellet could be shot into the center with a gas puff valve, timed to reach the center with the microwave pulse. This is something like the pellet technology of Inertial Confinement Fusion reactors. However this would be a strain for the current research program in terms of expense and complexity.

Another consideration in case a stable plasmoid develops is adding fuel while it is fully formed, instead of waiting for it to decay and forming another with fresh aerosol. This would be advantageous since the input power is entirely in formation of the plasmoid. The observed lifetime of natural BL is highly variable and probably has something to do with using up whatever fuel drives the reaction. Thus, to have a longer lifetime, more must be added, if possible. This fuel might be in the form of pellets to penetrate into the plasmoid, in the manner of feeding magnetically confined fusion plasmas with frozen hydrogen isotopes, or it might be better introduced as a spray of dust that is easier for the plasmoid to heat and incorporate into whatever process may be going on. Another possibility is an aerosol of particles fine enough to be easily suspended, such as thick smoke, that circulates through the reactor and is consumed by the plasmoid. Substantial mass is impractical to deliver in the form of smoke, vapor or gas, while powder on the order of a gram can fit in a sparker or a pellet. Liquid spray might also be possible and could deliver mass comparable with solids, but are limited in terms of possible operating pressures and temperatures external to the plasmoid.

The optimal gas pressure is entirely unknown. The most powerful, long-lived, and indisputably witnessed BL in history was the result of an undersea volcanic eruption in Japan. The huge plasmoid lasted over two hours, was many meters across, and terrorized an entire village. This implies that pressures in excess of atmospheric may be quite favorable for power production and duration. If as suspected hydrogen sulfide is a good fuel, the volcano could have supplied this in copious amounts. Organic matter is unlikely in this case. The existing seals on the antenna through-hull fittings cannot sustain positive pressures since they are simple rubber stoppers, and would have to be replaced for such experiments along with the equatorial seal which is undesirable in any case.

There are so many variables to explore and so little known of the physics that a suitable and especially optimal combination of factors will probably result from a fortuitous blunder.

VII. ALTERNATIVE GEOMETRIES

Spheres are more expensive and problematic than the ubiquitous cylinders. By using a lower frequency, which would be advantageous for power if not for economy of initial purchase, a cylindrical coil of similar proportions to the helical antennas (except of constant diameter) could cause breakdown along its axis. This could be in the manner of a Lisitano coil. Note that the initial breakdown and final glow for the ball reactor is inside the antenna coils. Then by addition of appropriate target material in the same manner as with the spherical ball reactor, it might be possible to have a more compact and simpler reactor. My thesis will go into more detail. This design is not practical for my reactor since it requires a single powerful microwave source, and the largest magnetron I can get cheaply is 1000 W.

VII. SUMMARY

The experiment is now functioning, and over the next two years I will be exploring a wide range of conditions in this unknown territory. Already there is anomalous behavior at atmospheric pressure, although since the anomaly includes the disabling of the video camera and thus my only tool for observation, it is unknown what is happening until further experiments occur. The reactor is simple, economical, and is proven already to cause a violent discharge at 3 torr in air. Further research might not lead to a ball lightning analog, stable plasmoid, or a new energy source, but there might be other uses for this geometry not yet anticipated. In addition this paves the way for a future SMC project should such become possible. Even a minor extension of plasma beyond the microwave power cutoff would be a major event worthy of much more research, and should be easy to detect. Thus despite my deficient plasma diagnosis tools, the critical observation is possible to record unambiguously with just a little extra instrumentation; hence this experiment could pave the way for future developments.

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