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ENERGY TRANSFER PROBLEMS OF BALL LIGHTNING

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ABSTRACT

The subject of the paper is the analysis of the energy transport phenomenon of ball lightnings,but momentum and charge transport phenomena are considered as well. The physical properties as energy density and transfer are investigated using several observer's accounts of interactions with different objects. It is shown that contrary to previous assumptions the ball lightning has negative electric charge, and very high internal energy density.

Both internal and external energy source models are analysed, and it is shown thatregardless to the details of a given model neither of them can explain actual observations. This has been validated by a well documented case study, and by several additional observations.

An entirely new, testable model is suggested, which is able to stand for all observed properties of ball lightnings, and it explains the cause of rarity of ball lightnings, and the reasons of the unsuccessful experimental efforts. It is shown that the plasma sphere is just a visible side effect of a more important phenomenon.

АННОТАЦИЯ

Статья посвящается вопросам передачи энергии шаровых молний. В работе исследуются также и потоки импульса и зарядов. Анализируются физические основы передачи и плотности энергии исходя из известных наблюдений. Доказывается, что, в отличие от существующих до сих пор представлений, заряд шаровой молнии является отрицательным, и в ней содержится энергия высокой плотности.

Анализируются модели, основанные как на внутреннем, так и на внешнем источнике энергии, и доказывается, что ни одна из них не способна описывать реальные случаи. Это утверждение в статье подтверждается описанием ряда известных наблюдений.

В работе представлена новая модель, которая отличается от предыдущих моделей и хорошо описывает все свойства шаровой молнии. С её помощью можно понять, почему шаровая молния является таким редким явлением, а также причину неудачи проведенных до сих пор экспериментальных работ. Данная модель показывает, что плазменный шар является лишь явлением, сопутствующим более важному процессу.

KIVONAT

A cikk a gömbvillámok energiatranszportjával foglalkozik, de az impulzus és töltésáramlást is vizsgálja. Esetleírásokat felhasználva elemzi az energia sűrűség és átvitel fizikai alapjait. Kimutatja, hogy az eddigi feltevésekkel ellentétben a gömbvillám töltése negatív és energiasűrűsége magas.

Mind a külső és belső energiaforráson alapuló modelleket vizsgálja és bizonyítja, hogy a részletekre való tekitnet nélkül egyik modelltipus sem képes leírni a valóságos eseteket. Ezt esettanulmányokkal, megfigyelésekkel támasztja alá. Egy új, az eddigiektől eltérő modell kerül bemutatásra, amelyik az összes tulajdonságot jól laírja és segítségével belátható, hogy az eddigi kísérleti erőfeszítések miért nem jártak sikerrel, és miért ennyire ritka ez a jelenség. A javasolt modell szerint a látható plazmagömb egy fontosabb folyamat kísérőjelensége csupán.

Contents

Introduction

The problem of ball lightning is a permanent source of interest for researchers for more than a century.

There are a great number of proposed models to describe its strange behaviour, but it met little success so far. A relatively large amount of observation data has already been collected, and a more or less consistent behaviour pattern can be set up along these. The accumulated data renders possible the deduction of qualitatively new conclusions.

Little attention has been paid so far to the description and modeling of ball lightning interactions with different objects of our environment.

The purpose of this paper is to have a closer look at these interactions, and to learn about the nature of ball lightning through these observations. The investigation of these interactions reveals the physical nature of B.L. more readily than any theoretical model. Two detailed and several qualitave case studies have lead to the major conclusions of the paper:

1) The problem of ball lightning is unsolvable in three space dimensions, because the energy and charge conservation is breached by all models, irrespective of the applied physical models.
2) The only way to resolve this contradiction is to introduce an additional space dimension, and in this manner all the properties of ball lightning can be explained.

The paper extensively used different compendiums of ball lightning observations· Stanley Singer [1], W N. Charman[2], I.P.Stahanov[3] Corliss[4], J.D.Barry[5], A G.Keul[6], R A.Leonov[7]. The ball lightning case in Habarowsk, observed and investigated by M.T Dimitriev, B.I Bahtin, V.I.Martinov[8], is the backbone of this paper. Its major parameters were simulated by calculations.

The attention is focused to the problem of energy and charge transport in the paper, and it will be discussed briefly why previous experimental and modeling efforts failed, and how is it possible to test the proposed new model.

For the readers, who are not familiar with the features of ball lightning phenomena, the case descriptions of appendix B are suggested to start with.

List of Symbols

T temperature
c specific heat
P power
U potential difference
I current
V volume
B magnetic induction
W work
A area
N total particle number
n specific particle number
Ry radiation yield
Q electric charge
v velocity
m particle mass
q heat flux
l path length
t time

Greek letters

λ heat conduction coefficient
ρ density, or specific ohmic resistance
ω frequency
ν viscosity
φ specific particle flux
ϕ particle flux
$\mathcal{E}$ electron energy
α heat transfer coefficient

Major Features of Ball Lightning observation

Due to the rarity of the B.L. appearance, our knowledge about its properties is only slowly increasing. Nevertheless there are enough written reports - by reliable observers as well - to establish quite confidently the characteristic features. Identical properties were found by independent researchers [1,2,3,7]. Additional collections of B.L. observation [6,12,13] confirmed the reality of the existence of its contraversial features as well. More than two thousand written reports have been accumulated during the last hundred years, but naturally it appears more frequently as not all the observations were reported to journals, and not all events were observed.

1.) Shape: Usually spherical, 80-90 % of the cases, or ellipsoidal - (always the longer axis is the rotation axis, not the shorter) 10-20 % of the cases. Occasionally the ratio of the longer axis/short axis is quite high, so the object is cigar-shaped.

In a few cases pear-shaped, and ring-shaped objects were observed as well.

Size: Diameter: 1 cm $< D <$ 1.5 m, however, rarely longer diameter were observed as well. The B.L. is spatially stable, but sometimes it became ellipsoidal from an initally spherical shape, and rarely the ball diameter is increasing or decreasing.

2.) Temporal stability: Contrary to the streak lightning, where the maximum "life expentancy" is much less than 1 sec, a number of ball lightnings are stable for more than a minute, that is, the difference could be more than two order of magnitude. Very rarely its lifetime is well over 10 min., that is, the life expectancy ratio is even higher. The temporal and spatial stability is a remarkable feature, and observations are not contradictory in this respect.

3.) Energy content: While there is a concensus concerning the previous features, the opinions are divided concerning the maximum specific output of the B.L.. Barry [9] estimates the energy density between 10^{-3} J/cm^3 and 10^6 J/cm^3, which is quite a wide range. The lower values were estimated by theoretical considerations, while the higher values were derived from the analysis of actual observations. Kozlov [10] estimates a much higher value for the energy content than Barry, based on different observations. The highest estimated value is given by Dimitriev [8]. There was no trace of radioactivity or alien material in the molten trace [8].

4.) Connection with ordinary streak lightning: While in most cases the B.L. has been observed during strong atmospheric electric activity, a small but not negligible part of observations were made before or after the stroms, or without any strom.

Some observers reported the appearance of B.L. when an ordinary lightning stroke the ground or conductor, or when the streak lightning split into two or more branches [3].

5.) Appearance and movement in closed spaces: One of the most striking feature of B.L. is that it can appear in closed space, even in metal cages, like aeroplanes, without damaging the walls. It can move through long tubes, sometimes it "flows" through small openings, contracting itself, later re-expanding to its original size. [9], [11].

6.) Appearance in groups: While about 90 % of the reported cases are single B.L. appearances, the rest is when two or more of them are visible, and sometimes they move together with the same velocity and same directions.

Occasionally a single B.L. falls apart into smaller ones, but they seldom unify into a single B.L. [1-6], [12].

7.) Rotation: Usually the shape of B.L. is perfectly round, and its colour is homogeneously distributed, uniform. Therefore it is hard to judge whether it is rotating, or not.

Despite this difficulty, some observers reported a definite rotational movement, when they had the opportunity to watch B.L. movement from a close distance [13].

8.) Aura, Halo: Several observers reported that a halo surrounded the "body" of B.L., and sometimes straight or spiral-shaped arms, protrusions emerged from body, often sparks were emitted [1,2,3,8,13,14].

A characteristic hissing sound accompanied the spark emission resembling to an arc welder.

9) Sound and electric effects: the formation of B.L. is accompanied with an explosion like sound while the extinction is not always, the B.L might disappear without any noise, or with a loud bang. [1 6]. The B.L. moves and behaves like an electrically charged sphere [7].

Several observers noted mild or strong electric shock or prickling at the time of B.L. collapse. Sometimes the smell of ozone or No_2 has been noted [3].

Electric circuit breakers, fuses are frequently melted when the B.L. disappears with a detonation, but never when it vanishes silently.

10.) Magnetic effects: In some cases strong magnetisation has been reported after the impact of B.L., 1 while in other cases there is no apparent magnetic effect. [13].

11.) Characteristic movement: the B.L. is usally stationary, or moves with a modest velocity, but occasionally very high velocities were reported.

While most observations were made on ground level, several B.L. has been reported on high altitudes, from airplanes. [1-6]. The B.L. usually ascends from higher altitudes, and rarely lifts to high altitudes. When it is on the ground level, it moves horizontally.

12.) Effect of wind: There is a general agreement that wind speed and direction has little or no effect on the movement of B.L., some observers noted that it moves against the wind direction. [1-6].

13.) Colour: In most cases white or red colour has been reported, but blue, yellow, green and violet has been observed as well.

Occasionally the same B.L. has shown temporal change in colour, [3] or it could be transparent as well. [13].

14.) thermal effects: Observers standing quite near to the fall did not feel heat [1,2,3,6] but scorching heat was felt when the observers reached out for the "body" of B.L. Significant thermal damage has been reported after interactions with solid, liquid targets, objects. [1-10,14]. It is important to note that B.L. may exist under water as well [1,2,3] or in heavy rain [8].

15.) Laboratory replication: Despite some limited efforts so far no successful laboratory B.L. observation has been reported.

Causality, conservation laws and Ball Lightning

There are no successful theoretical models or laboratory test so far, and it is not for the lack of trying. There is a general agreement, however, that the key of the problem is to understand the energy transport mechanism, because all other features - like temperal and spatial stability, formation and collapse, etc. - are the consequences of energy transport.

There are two possible locations for the energy source, - internal or external - and these will be examined from the viewpoint of conservation principles and causality.

Internal energy source:

A) The very first problem to be tackled is causality, because a number of observers have seen the formation of B.L. without any apparent reason in clear weather. For the internal energy source models this is a clear-cut breach of causality.

B) As the wind has no effect upon the B.L. - it is not airborne - the momentum conservation principle is breached, unless some strange propulsion mechanism is assumed, which is able to compensate the effect of momentum transfer.

C) The B.L. usually floats in the air, but it can immerse into liquid. Therefore it antagonizes the principle of action-reaction, or it sets its own density to that of the ambient.

D) The internal energy content of plasma is low, and it can not stand for the huge amount of energy released in interactions with solid objects. Thus the conservation of energy is not fulfilled for the internal source models.

E) The B.L. behaves like an electrically slightly charged sphere, but when it is terminated by an explosion a large amount of charge is released - thus confronting the principle of charge conservation.

All of these issues are insurmountable problems for any internal energy models, but the causality breach alone excludes the feasibility of these models. This statement is valid for any of these models, no matter how tricky or ingenious it is in the details.

External Energy Source Models

In this case the causality, momentum transfer, and density problems (A,B, C) are not raised, but there are serious problems here as well.

The observers categorically state the lack of heat sensation near the B.L. There is no reason to assume that the air is heated by the energy source, but not the human body. As the plasma sphere cannot store significant amount of energy, the supply must be continuous. Lacking any indication of this energy supply, the energy conservation is not satisfied. The situation is the same for the charge conservation as well. While there is ample evidence for the continuous electron emission, and a large charge release after the collapse, there is no evidence for the charge absorption by the B.L. and charge transport to the B.L.

The only likely candidate for external energy source is short-wave EM radiation, but it could melt only electrically conductive materials, while B.L. melts and evaporates glass as well.

That is, energy and charge conservation is b reached in the case of external energy source models as well, and there are problems with the means of energy transport as well. (Apart from these fundamental problems, there are a number of other difficulties as well, mainly in the field of plasma physics. These will be listed briefly in the concluding remarks, to show that the visible plasma sphere of the ball lightning is just a by-product of a primary phenomenon).

The analysis led to an apparent deadlock, because conservation principles and causality have to be satisfied, but regardless of the energy transport mechanism, according to the observations–conservation principles are breached. The conservation principles and causality are the cornerstones of our knowledge, and there is no reason to assume that they are not valid for the very case of ball lightning.

On the other hand ball lightning exists, its existence is supported by a large number of independent and simultaneous observations, and it leaves a definite damage pattern after interactions. It exists when it should not exist

The contradiction can be resolved without giving up either the conservation principles or the observations - but at a price. The study of actual observations will help to understand the physical features of ball lightning.

Features of energy transfer in ball-lightning interactions (first case study)

During a heavy storm and rain a 1.5 m diameter, orange red, very bright ball lightning appeared above the trees of a park in Habarovsk, Siberia [8], on 24th of August, 1978 The B.L. emitted sparks and hissing sound was heard all over It slowly descended through the branches of the trees, then suddenly dropped into a small pond. There was a bright flash, the B.L. jumped up, and soon exploded. The whole event took about 1.5 min. time. The electric wires were damaged in a 100 m radius.

The pond disappeared, and the ground has been melted into a grainy slag, uniformly through about a 20-25 cm deep and 1.5 m diameter spot, of $\sim 0.4\ m^3$ volume. The interaction with the soil took about 0.1 sec. No radioactive trace or alien matter has been found. [8]

M.T.Dimitriev, B.I.Bahtin and B.I.Martinov collected the molten soil, and calculated the necessary energy input to melt the soil - neglecting the evaporation heat.

Their calculation yielded a $\sim 10^9$ Joule energy content, ($\sim 600\ J/cm^3$), and 10^{11} W power, ($\sim 6.10^4\ W/cm^3$).

(During the same storm an other B.L. struck a 7000 lit. cauldron, and boiled off part of the water. The estimated energy content was about $8.3.10^9$ Joule in that case).

The artifical simulation of the energy transfer has not been successful: using the ambient, uneffected soil for the experiments, the heat radiation, direct current heating, and high voltage pulse heating could not replicate the outcome - and high frequency heating was partly successful only when 30 % copper has been added to the soil sample. Without copper the heating was unsuccessful.

The analysis of the B.L. impact revealed that the soil has been uniformly melted.

What sort of energy transfer mechnism could produce such an effect?

Let us examine the possible mechanisms:

a.) Transient heat conduction from a plasma sphere

The soil is treated as a homogeneous isotropic layer of SiO_2 and one-dimensional transient heat conduction is considered.

The equation of 1-D heat conduction is as follows:

$$\frac{\lambda}{\rho \cdot c} \cdot \frac{\partial T}{\partial x} = \frac{\partial T}{\partial t}$$

The initial and boundary conditions are the followings:

$$T_{surf} = T_{x=o} = \text{surface temperature to be calculated}$$

$T_{x=0}$ is assumed to be independent of time.

$T_{end} = T\Big|_{\substack{x=0.25\ m \\ t=0.1\ sec}} = 1700\ {}^{o}C$ - temperature of melted glass at the bottom

The solution has the following general form:

$$T(x,t) = T_{surf}(t) + (T_{end}(t) - T_{surf}(t)) \cdot \frac{2}{\sqrt{\pi}} \int_0^{\eta} e^{-\eta^2} d\eta$$

where $\eta = \dfrac{x}{2\sqrt{\dfrac{\lambda}{\rho \cdot c} t}}$ (see Fig 1.)

Substituting the above geometry, and using the material properties of SiO_2, the surface temperature $T\Big|_{\substack{x=o \\ t=0.1\ sec}} = T_{surf}$ can be calculated. For the given conditions, $T_{surf} \gg 10^{15}\ {}^{o}C$ is obtained. At least t=40 sec is necessary in the case of $T_{surf} = 10^{15}\ {}^{o}C$ to melt 25 cm thick layer of dry SiO_2.

In the calculations the soil-water evaporation heat requirement has been neglected (however, it is a considerable value).

It is obvious that at such a high temperature the soil would evaporate, and heat conduction can't be responsible for the observed uniform melting. It has to be noted that the real period of heating was much less than 40 sec, so the above temperatures are only a gross underestimations of the real values, if heat-conduction from a plasma sphere is considered as an energy transfer mechanism. Therefore heat conduction from a surface can be discounted as a possible mechanism involved in B.L. interactions. (In the above calculations an $\alpha = \infty$ heat transfer coefficient has been assumed, which is again a gross overestimation. This fact underlines again that the observed soil melting can't be an energy transfer through surface, it must be a sort of volumetric heating).

b.) Heat radiation

Solid materials absorb heat radiation in a very thin (< 0.1 mm) layer, then the thermal energy is transported by conduction only, so the previous analysis and results are to be applied, therefore radiation is also discounted.

c.) Heating by electric current

The specific heat generation rate is a function of current and specific resistance

$$P = U \cdot I = \frac{U^2}{R}$$

The U potential should be about 10^{10}V assuming $\rho = 10^{11}\,\Omega\,m$ specific resistance. Apart from the high value of the voltage, the shape of the melted volume can't be explained with this mechanism, because it is far too regular. Lightning traces show always irregular conduction channel forms, like roots of a plant.

d.) Eddy current heating

An other possibility for volumetric heating is to use rapidly changing magnetic fields for eddy current induction, which in turn dissipates, therefore the soil is heated.

When the electric resistance of the heated medium is high, the specific heat generation rate is

$$\frac{P}{V} \approx \frac{\omega^2 d^2 \bar{B}^2}{24\varrho}$$

where ω is the frequency of the inducing magnetic field, d the object diameter, $\bar{B}$ magnetic field induction (spatial average), ϱ specific resistance.

The following values are used for the calculations: ω =100 MHz using streak lightning data of Singer [1] pp 144. d=1.0 m although smaller soil-particle grain-size should be used as well.

As $\frac{P}{V} = 3.10^{12}\ \frac{W}{m^3}$ from Dimitriev's observation [8]

$\varrho = 10^4\ \Omega\,m$ (melted glass)

With these values, $\bar{B} \sim 0.1\ V_{sec}/m^2$ is obtained, which is a high value if it is compared to the usual $\bar{B} \sim 0.01\ V_{sec}/m^2$ value of air-core coils used in laboratories.

But if $\varrho \cong 10^{11}$ ohm m (dry quartz sand) is used, $\bar{B} \sim 10^9 V_{sec}/m^2$ is obtained, which is a very high value. But this high electric resistivity value must be considered also, because when the wet soil is heated, after the evaporation of water the electrical resistance is increased to this level. If the temperature is increased further, this resistance is decreasing again to the value of melted glass. Dimitriev et al [8] were unable to pass this threshold, and added copper to the soil. But the ratios of conductivities are 10^6 for melted glass/copper, and 10^{13} for dry sand/copper.

Therefore the eddy current heating can't be considered as the energy transfer mechanism behind the B.L. - soil interaction.

e.) <u>Particle beam heating</u>

The last and only remaining possibility for rapid volumetric heating of electrically conducting and insulating materials is particle beam absorption. (Laser beam radiation (E.M. radiation) is not considered, because it is never ball shaped.)

Practically only electrically charged particles can be considered, that is ion, proton and electron beams. The ion and proton beams create strong radiactivity after absorption, but Dimitriev et al [8] did not find any trace of it, and chromatography excluded further the possibility of involvement of ions.

Therefore, the most likely candidate to cause such an effect is an electron beam, and other circumstances seem to support further this idea; namely, the manner of absorbtion of fast electrons in solids. Most of the electrons absorbed within a finite length, (characterised by the given material and electron energy) and it is not gradually absorbed as in the case of other E.M. radiations. Thus the finite depth of melted soil, its relatively sharp contours indicate that such an effect can be caused by a high energy, relativistic energy beam.

The given 20-25 cm thick SiO_2 layer can stop a ~200-300 MeV electron beam, in the same manner as it has been observed (the stopping power is ~3 g/cm^3).

As the total energy absorbed in the soil has been $W \sim 1.1.10^9$J, thus the absorbed particle number can be calculated as follows:

$$n\left[\frac{1}{m^2}\right] = \frac{W}{\varepsilon_{beam} . Ry . A} = \frac{1.1.10^9}{0.5.200\ \text{MeV}.2.25\ m^2} \cong 3.0.10^{19}\ \frac{\text{electrons}}{m^2}$$

Where ε_{beam} is the initial beam electron energy, (200 MeV) Ry is the radiation yield coefficient ~(0.45). A target surface (2.25 m^2), W target thermal energy generation.

The beam current is: $I=\frac{\emptyset e}{\Delta t}\cong 44$ A , when $\Delta t=0.1$ sec is used. It has to be noted that Δt has been observed visually, and it could have been significantly shorter as well, or a little longer too.

Although the heating and melting of the soil and its shape could be explained as a consequence of a Relativistic Electron Beam (REB), the absorbtion of such a beam has not been observed in ball lightnings. At this point an internal contradiction have appeared again, there is no apparend physical mechanism which could be responsible for the physical features of the impact. This is the point, where some hypothesis is to be introduced, which could bridge the gap between the observations and conservation principles. The hypothesis should be testable, it should explain the major features of ball lightnings, and it should not contradict causality and conservation principles, it should explain why previous modeling efforts and laboratory experiments failed. But first of all, it has to explain the energy and charge transport mechanism, which seemed to be impossible for both internal and external source models.

There is only one chance left: Our notions about the space-time is to be reexamined. Contrary to the taciturnly assumed three space dimensions the existence of an additional space dimension has to be hypothesized.

The problem is similar to that of the squaring the circle; because lots of effort has been devoted to solve the problem, but it was realised after a while that it is unsolvable.

The enigma of ball lightning is unsolvable in three space dimensions - theoretically and experimentally as well. This explains the fruitless previous efforts in this field, and only this could resolve the previously discussed internal contradictions. This is the price to be paid for the bridging the gap between practice - observation results - and the time-honored conservation principles.

The rest of the paper will be devoted to outline a multidimensional B.L. model, which is rather heuristic at this stage of the development.

Multidimensional models

At this point a short detour is to be made, in order to clarify the feasibility of the multidimensional model, and to outline very briefly some of them.

Our daily experience tells us that we are living in a three-space-dimensional (3D) world. However, the basic physical laws have no restrictions concerning the number of space dimensions, they could be extended to arbitrary number of space dimensions in principle.

Additional dimensions could mean a more simple, unified manner of basic interactions. Basically it could yield a more simple, not a more complicated treatment of interactions.

The general relativity theory succesfully describes the interactions of the gravity field, in a classical, (non-quantum) form, using second order differential equations. Non-gravitational fields are described universally by the methods of quantum mechanics, by non-classical wave mechanics.

There were several attempts to unify these theories, to obtain a general treatment of all interactions. Research started from both possible directions:

a.) to quantize gravity field, to extend wave mechanics to gravity. In this case three space dimensions are to be used, like in the case of weak, strong and electromagnetic interactions. The followers of this line of thought are satisfied with our ordinary experience of the 3D world. [16]

b.) The other line of thought follows a classical, non-quantum method to integrate all physical fields into a geometric structure, like the general relativity theory. This geometric structure has to form a more than 3D structure, it should explain quantum effects, and the properties and interaction of elementary particles as well.

As it is well known, no successful theory has emerged from the above lines, although there were several attempts. One of the purposes of this paper is to indicate that multidimensional models do have physical background, such phenomena happen in nature, therefore it is worth pursuing this line of thought, despite the apparent slow progress.

The capability of a multidimensional model is determined by the choice of the local topological properties of the space-time manifold.

Multidimensional models have been chosen intuitively, not as a consequence of experimental observations. (Therefore their naturalness is more of a matter of taste, even the application and merits of finite dimensional models are questioned.) Consequently any experimental observation of the topological properties of the space-time manifold is important not only for practical reasons, but to help the creation of a successful theory as well.

Apart from the topological properties of the space time, there is an other fundamental issue: stability. The everyday experience suggests that there is no additional space dimension or if it does exist it must be very small. However, if matter is stable only in three space dimensions, while unstable in higher dimensions - the absence of multidimensional phenomena is obvious. (Indeed, all natural phenomena can be explained in the 4D space-time manifold in the inanimate world - except ball lightning). The work of Ehrenfest [17] and Tangherlini [18] showed this instability in classical and micro-physics. That is, any phenomenon taking place in more than three space dimensions is inherently instable, and it will return, "collapse" back to 3D (Practically the same is true for less than 3D as well).

This means that the 3 space + 1 time dimensional universe is distinguished compared to any other space-time manifolds, due to the issue of stability. Consequently the universe could have a more complex space-time topology than our 4D space-time manifold - that is, it will be embedded into it, like a 2D surface into a 3D space. Our perceptible 4D space time will be a "membrane", a subspace in the more than 4D model. The most important consequence of this stability is that matter is inhomogeneously distributed in the universe, it is concentrated in a 3 space dimensional "membrane". However, the uneven distribution of matter will not disturb the fields, they will "fill" the whole space regardless of its topology. Therefore the issue of stability has no direct consequence upon the field equations, they can be used without any modification. The fact that this instability issue has been neglected had an effect upon the choice of space-time topology. Very complicated topologies were assumed in order to explain why we are unable to detect the presence of higher space dimensions.

The first, and up to this day most important step was taken by Theodore Kaluza [19] who chose an additional, curved, closed cylindrical space dimension in order to circumvence this problem. He was not aware of Ehrenfest's work on stability because it was published later. Kaluza realised, if the number of space dimensions is increased, then the number of tensor components in the Einstein equation will increase in such a manner that a single potential tensor generates a universal field wich splits under normal circumstances into a gravitational and electromagnetic part. Thus, the geometrization of electromagnetic interactions was rendered possible by increasing the number of space dimensions. His work has been improved by Oscar Klein [20] in order to involve the explanation of quantum effects as well. Their line of thought influenced several other physicists, and the idea of a more than 4D space-time [21] became one of the accepted possibilities to solve the unification of interactions.

It has to be mentioned briefly, that there are other type of attempts to solve the same problem, that is, not more than three space coordinate(s) are chosen, but additional time coordinates (Cole [22]), or mass is considered (Hagston, Cox[23]) as new type of dimension. The number of dimensions is increased in some models up 11, so the number of different multidimensional models is too many even to mention all of them. This clearly shows that there is a need for experimental results, which will quide further work in this area at least in the proper selection of the correct topology of the space-time manifold.

The existence of ball lightning indicates that there is at least one more unfolded space dimension, but the matter of the universe is concentrated in three space dimensions, as stated by Ehrenfest. Consequently further on only such models should be developed, which have at least a five dimensional (non folded) space-time manifold, apart from additional compact space dimensions.

The rise of ball lightning

From the different properties and mechanisms of ball lightning perhaps the formation is the most difficult to understand, but at least a heuristic multidimensional model can be given. (The word multidimensional will be used to note a more than 3 space dimensional space-time manifold). The curvature is the consequence of the presence of a large mass, plus energy transport.

The general relativity theory predicts the existence of "curved" 4D space-time. The existence of an additional space dimension will simplify the understanding of the concept of curved 3D space.

The introduction of an additional space dimension should be followed by the extension of electrodynamics to the new topology of space-time.

The electrodynamical consequences of a 4D space are discussed in [24] to some degree. As it is very hard to grasp a 4D geometry, a simplified 2D-3D analogy of 3D-4D phenomena will be used. Obviously a rigorous treatment of the problem will be necessary later in order to verify the assumptions made in this paper. In Euclidean space the qualitative results of an experiment are independent of the distance from the field source. (See Fig.2a).

In a curved Riemann space (where the Euclidean approximation is invalid) new field components appear. (See Fig.2b).

In this case the farther is the field source, the larger is the inclination angle of the new component, the ratio between the so far nondetectable horizontal and the vertical component. That is, a remote and strong field source is necessary in order to detect the consequence of such an effect in a curved space.

(For this purpose ideally, lightning around a black hole would be the best.) Apparently the gravity field of the Earth can produce such an effect - inasmuch very strong currents are used.

The first effect to be explained is why and how the charged particle leaves the 3D space.

The 2D curved space analogy is more simple to grasp and to sketch, and it is shown on Fig.3. There are two possible mechanisms.

a.) The strong electric current, originated in "1", creates a horizontal component in "2". If the velocity of the charges is perpendicular to B_h, the resultant Lorentz-force will move off the particles from the curved 2D space. (The concept of Lorentz-force is extended here in a straightforward manner).

b.) The case is the same as before, but the direction of the current is changing in point "2". At point "3" the magnetic field has a horizontal component and a perpendicular velocity component. The Lorentz-force will move the charge in the same manner as above, off from the 2D surface.

The same qualitative arguments can be extended to a 3D-subspace,"surface", embedded into a 4D space.

It is clear, if this effect is to be simulated, two remote current generators are to be used, optimised for the maximum of the B_{42}, B_{43}, B_{44}, 4D components of the magnetic field.

(In the case of 4D, these will be 6 components of the magnetic field.) Based on actual observations of B.L. formation, the process is reconstructed as follows:

a) A very long high-current streak lightning hits a target. (The lightning has to be long for the higher-dimensional magnetic components to appear due to space curvature).

b) Part of the electrons will be accumulated at the target, creating a temporary but significant electric field around the impact site.

c) Other part of the electrons will be "lifted" to the 4th space dimension due to the abovementioned reasons, and move towards the impact site. Near to the impact site 4D electrons decelerate in the electric field of the impact site, and changing course accelerate again. The path of an individual electron is determined by its own energy.

d) If the electrons are accelerated above a threshold energy, the inward Lorentz-force will be higher than that of the repelling Coulomb-force, and the electrons will form a self-constricting temporarily stable beam. During the initial period space charge compensation by positive ions might help the formation. (See Appendix A).

e) The high-velocity Relativistic Electron Beam (REB) is moving in the weak geomagnetic field, and it will form a closed ring. The ring will penetrate twice through our stable "3D membrane". The first penetration site will be near to the impact site of the streak lightning, the second site will be rather far away, at the other end of the ring diameter, (See Fig 3d). This will be the second penetration site. The ring diameter is determined by the electron energy and the geomagnetic field intensity. (The formation process is described qualitatively in some case studies of Appendix B).

It is not yet clear at this moment how to take into account the effect of 3D stability discussed previously. This would be necessary to calculate the threshold value of the Lorentz-force enough to remove the charged particle from 3D space.

It is quite clear that <u>only free electrons</u> could be removed, not those in any potential well.

The most important will be the loss due to penetration through the 3D "membrane". This will be collisional and bremsstrahlung.

The magnetic field of Earth renders possible the "storage" of the beam energy. Without geomagnetic field the electrons would leave our 3D space, but the beam would fall apart soon, the individual electrons returning separately to our stable 3D space.

The properties and processes in ball lightning based on the ring model

The properties of the B.L. are the direct consequence of the above-described multidimensional "ring" model. The B.L. has an external energy source in this physical model.

The visible ball lightning is a trace of the four dimensional high-energy, self-focusing relitivistic electron beam penetrating through our 3D "membrane".

The shape of B.L. is a consequence of this effect. When a 4D cylinder, the electron beam, penetrates through a 3D subspace, their segment is a sphere. The diameter of the sphere will be the beam diameter.

(2D analogy - a 3D cylinder, orthogonal to a 2D plane, will cut a circle, where the diameter is that of the 3D cylinder. See Fig.4.)

If the 4D beam is not orthogonal to the 3D space the common segment will be an ellipsoid, which has been several times observed.

The smaller axis will be equal to the beam diameter, while the ratio of the longer and smaller axis corresponds to the beam inclination angle. The occasionally observed pear-shaped B.L. contains positive ions as well, and these ions remain in the ring as long as the Coulomb force, attraction between the electron beam and the positive ions, is greater than the centrifugal force. As the electron beam will continuously increase the ion velocity through collisions, groups of ions will leave the beam from time to time, thus this type of B.L. is instable. The absorption of positive ions will influence beam equilibrium through charge compensation as well.

Near to any inhomogeneous electric or magnetic field the beam inclination angle to the 3D membrane will change, thus the shape of the B.L. will change, it will be ellipsoidal.

The shape of B.L is a geometrical consequence of 4D beam - 3D space intersection.

a) Spatial stability

As long as the electron beam is stable, the B.L. will exist, so the crucial issue is the multidimensional electron beam stability.

There is ample experimental evidence that in 3D space stable, self constricting REB could exist,(See Appendix A,) and its guiding principles can be extended to more than 3D as well. In vacuum, for a given space charge density, there is a critical minimum speed, the electron beam will diverge if this criterion is not met.

If the beam must pass neutral or ionised gas, further destabilizing effects arise, the electron speed, energy, must increase to a higher stability limit.

There is no stable propagation through thick solids, the beam will be scattered, its energy will be absorbed in the solid.

If the beam has high energy and space charge density, it will exist for a long time, while a part of its energy is continuously lost due to collisions with air ions, and it will disappear through continuous fading. When the beam is just over the stability limit, its existence will be shortly terminated reaching this limit. Coulomb-forces, overcoming self constricting Lorentz-forces blow up the beam, and the electrons will be scattered, causing a feeling of electric shock to nearby observers.

In principle, the parameters of streak lightning are sufficient enough to create a stable REB, that is, to transform from 3D streak lightning into 4D ring lightning, or electron beam.

$$I_{max} \sim 3.10^4 A$$
$$U_{max} \sim 10^9 V$$
$$W_{max} \sim 10^9 J$$
$$Q_{max} \sim 500 \text{ A sec}$$

In the case of 3D in order to compensate Coulomb-forces by the Lorentz self field, the stability criterion $\frac{\nu}{\gamma} \geqq 1$ is to be met:

where $\nu = \frac{I\,[A]}{17000\beta}$

$$\gamma = 1 + \frac{eV}{mc^2}$$

$$\beta = \sqrt{1 - \frac{1}{\gamma^2}}$$

for a 200 MeV energy (Habarovsk case) $\gamma \sim 200$ therefore $\beta \sim 1$.

At present the 4D stability criterion has not been formulated yet, but it will be necessary in order to estimate the threshold current. The 3D criterion yields a high current, but it is not applicable. There is an independent method to estimate the beam current as well.

Given the electron energy ~ 200 MeV, and the magnetic induction of the Earth, the beam ring diameter can be calculated from the equilibrium of Lorentz-force and centrifugal force

$$e(v \times B_E) = m_{el} \cdot \frac{v^2}{r_{ring}}$$

For our case, accounting the relativistic mass increment: $r \sim 1.1.10^4$ m.

The electron density of the beam is:

$$\rho_e = \frac{\emptyset}{2r_{ring}\pi} = 5.10^{15} \ \frac{\text{electron}}{\text{m}}$$

The electron flux is: $\emptyset = \rho_e v = 1.4.10^{24} \ \frac{\text{electron}}{\text{sec}}$

so the beam current loss will be: $I = \emptyset\, e = 2.2.10^4$ A
if the beam is absorbed on a solid object totally.

It has to be emphasized that in the Habarobsk case not all the beam current has been dissipated in the soil, only a part of it, because after the impact upon the soil the B.L. jumped off from the interaction site, therefore the total beam current is higher. The beam energy loss has been detected, not the total current in the observed case.

During the existence of B.L. some of its electrons will be lost due to scattering, but positive ions could be absorbed by the beam, in principle.

The scattering of air particles, beam energy loss and absorption on solid targets will influence beam stability, thus the beam diameter. Therefore the beam diameter can change in time, and such effects have been observed. [1] pp 73.

Beam instability could cause filamentation, that is, the beam will split into smaller filaments, consequently, a 3D observer will note that a larger ball will fall apart [12], [1], pp37.

The opposite process may occur as well, that is, the recombination of filaments, [1] pp 37. It has to be noted that the volume of the observed smaller spheres is significantly smaller than the original ball volume. This indicates further that the B.L. is not a plasma blob, where some sort of volume conservation could have been expected.

If the beam, or ring, is perpendicular to our 3D plane, their segment will be a sphere, otherwise the inclination angle is less than $\pi/2$. While both formations are spatially stable, the latter, more general formation will be energetically less favourable, the particles will travel through a longer distance in our 3D space, thus loosing more energy. Therefore elliptical B.L. has a shorter lifetime, and its observation is more difficult.

The temporal stability, and its relation to energy transport will be discussed later.

b) Energy content

By now it is easy to resolve the contradiction over the energy content of B.L. It is clear that the energy is not stored in the visible sphere, but in the invisible, ring-shaped electron beam. The energy transferred to the ambient depends heavily on the mass-stopping power of the material, where the beam is passing.

As the difference between the density of the high-temperature, ionised air and solid material could be more than six orders of magnitude, the energy transfer or dissipation will change accordingly. While the B.L. is relatively harmless when in the air, loosing a small amount of energy to the ambient, in the case of a solid material it will transfer much more energy to the object.

This phenomenon caused the controversy about the energy content, that is, essentially the same B.L. could be harmless or dangerous, depending upon the circumstances.

Obviously there could be real differences in energy content, but then the initial beam energy is to be considered.

When the B.L., that is, the electron beam, is passing through air, it will heat, ionise it, thus decreasing the air density significantly. The stopping power of the hot, rare, ionized gas will be very small, therefore the beam energy loss is not very significant.

The most important issue for the energy loss calculations is the temperature of ionised gas. The plasma temperature is $\sim 3.10^4$ ^{0}K in streak lightning, $\sim 10^5$ ^{0}K in magnetically confined electric arcs, but substantially higher in REB, heated adiabatic 3D plasmas.

In principle, the maximum plasma temperature could be

$$T_{max} = \frac{2E}{3k}$$

when the beam energy is dissipated entirely in the target, for an adiabatic case (k is the Boltzman constant.).

For E=200 MeV, this yields $T_{max} \sim 1.5.10^{10}$ K.

Obviously this is a physically unrealistic value, because the temperature will be less, due to the inefficiency of coupling and different types of energy losses:

A) energy loss due to heat conduction.

$$\dot{q}'' = -\lambda \frac{\partial T}{\partial x}$$ where the λ heat conduction coefficient depends on the given material and its density.

B) convective energy loss, because high energy ions and electrons leave the B.L. volume. This type of loss is substantial in the case of gases and liquids, and negligible for solids.

C) The heating effect of Bremsstrahlung is negligible for gases, and very small for liquids and solids, but depending on the beam energy and target density, the total loss could be significant.

D) Heat radiation is significant for solids and liquids, but marginally important for gases, because they are usually transparent for heat radiation, they emit only in narrow bands. Therefore the black-body approximation is incorrect. [3,5]

When the beam interacts with solids, the bremsstrahlung is leaving the target, that is

$$E_{out} = \dot{\varphi} \cdot E_{beam} R_y$$
$$E_{in} = \dot{\varphi} \cdot E_{beam}$$

In the case of gas target and steady state conditions the situation will be more complicated. There will be convective heat loss, primary and secondary Bremhsstrahlung and a loss term due to the scattering of electrons from the beam. The energy requirements of these losses are continuously consuming the beam energy.

It has to be noted that in the plasma sphere, in the impact volume, the T_e electron temperature and the T_i ion temperature will be different, and they could be assumed as two different types of gases in interaction.

The gas temperature will be the ion temperature, and the thermal loss is due mainly to turbulent natural convention, which depends mainly on the temperature difference.

$$E^{3D}_{conv} = \alpha(T_{ion} - T_{ambient})$$

where $\alpha \approx 0.135 . (\frac{1}{T} g \frac{\nu \rho c}{\lambda})^{1/3} \frac{\lambda}{\nu^{2/3}} (T_i - T_{amb})^{1/3}$

is the heat transfer coefficient, and ν is the gas viscosity.

There will be another, unusual source of loss, E^{4D}_{conv}, collisional diffusion of ions towards the 4th D. This will cause a sort of "suction" or jet pump effect. At this stage of development it is hard to estimate it, and it will be neglected. It would be necessary to estimate at first the Ehrenfest - Tangherlini stability effect, then considering the momentum transfer between the 4D electron beam and the ionised gas, then this term could be calculated with 4D Monte-Carlo method.

The electron losses should be calculated in a similar manner. If the electron scattering loss term in neglected, that is, only thermal loss is assumed, the ion temperature of the plasma sphere can be estimated. Another crude approximation is that beam electrons interact through a chord in the sphere while this is definitely not a good approximation. (See Appendix E for details).

Noting the previous simplifications, the energy conservation equation will be:

$$\varepsilon_{coll}(E) . \rho_{air}(T_{ion}) . \ell_{air} R^2 \pi . \dot{\varphi}_{beam} = 4R^2 \pi \alpha (T_{av})(T_{ion} - T_{ambient})$$

where: $\varepsilon_{coll}(E)$ is the collisional mass stopping power as a function of beam electron energy; ℓ is the average path length of electrons in the sphere of the B.L.; R is the beam and ball radius; $T_{av} = 1/2(T_i + T_{ambient}) = T_i/2$ is the average ion temperature.

The calculation yields: $T_i \approx 5.10^6$ ^oK as the equilibrium ion temperature.

It has to be noted again that this value is only a very crude estimation, but a better result requires numerical calculations, and more sophisticated modeling.

It is clear from the result that it is inacceptable, it yields such a high temperature at which atoms are fully ionised. But B.L. observations are associated always with light-emitting luminous phenomena, therefore the temperature, and the degree of ionisation must be much lower. The ion temperature is significantly lower in the B.L. volume than the estimated value, consequently the neglected electron loss term is significant, and the collisional mass stopping power has to be re-evaluated for multidimensional ionisation interactions. Therefore the heat content of a B.L. is insignificant, the accumulated heat and the heat losses are much less then calculated. Consequently the beam might move rapidly, and ionise the air continuously even if the air is rapidly flowing through the impact volume.

When the beam energy is dissipated in water, the calculation is more difficult, because the evaporating water creates superheated and saturated vapor bubbles. Therefore, inside the sphere the gas approximation is to be used noting the effect of penetration length.

c) Temporal stability and termination

The temporal stability is a characteristic feature of B.L. observations. There is not a single experimental result where stable plasma has been observed without external energy supply.

For 3D plasma the recombination has to be very quick for several reasons, as attraction between positive ions and negative electrons, cooling due to the second law of thermodynamics, etc.

The "lifetime" of a B.L. is determined by three major factors: the initial energy content, the stability (threshold) energy content and the sum of power losses.

The initial energy content is determined by the average beam electron energy (in the ring), and their total number. The energy content at the stability threshold is determined by the beam current in the ring. When it drops below the critical level the beam is not self-constricting any more, it will fall apart. The different loss terms have been discussed previously, as ionisation, heating, primary and secondary bremsstrahlung, scattering. The energy balance yields the t lifetime:

$$W_{initial} - W_{critical} = \int_0^t \sum P(t)dt_{loss}$$

For the Habarovsk case, considering the thermal losses only, $t \sim 300$ sec is obtained. This lifetime has been shorter due to the intaraction with the soil, which increased the beam loss considerably.

At the end of the lifetime, the B.L. is terminated either silently, or explosively. As it has been discussed earlier, the ring has two penetration sites, and the beam terminates with an explosion at the impact site, where the stability criterion is not met at first time during the existence of the B.L. At that penetration site, the $W_{critical}$ is released, but in a very peculiar manner: the beam electrons are coming mainly from the 4th space dimension, not from the visible B.L. impact site. Consequently, electrons may appear from an exploding beam even inside a Faraday cage, when the B.L. is outside of it. If somehow a B.L. could be covered entirely by an electric insulator, the observer would note that after the B.L. termination electrons appear everywhere despite the insulation. Summing up: walls can not hinder charge (electron) transport during the final, exploding period.

While the B.L. is terminated at one penetration site with such spectacular effects, it will vanish silently at the other site, as its power supply has been terminated. The recombination of the ionised plasma will be quite quick, and practically noiseless, only some trace of O_3 and brownish NO_2 will be left, without electric aftereffects.

The chance for the "explosive" termination is always higher at the penetration site, where the beam loss is maximal, that is, at interactions with solid objects. Otherwise there is about a 50-50 % chance that explosive or silent termination will be observed.

d) Aura, halo around ball lightning

Previous considerations have shown that a part of the beam is continuously losing energy through scattering. The ball surface will be therefore a virtual cathode, it will be a source of electric current. This current will cause the appearance of a dim "halo" around the B.L.

For the Habarovsk case the current density can be estimated based on the amount of dissipated charge.

As $Q=\phi e \sim 3.10^{19}$ electrons.$1.6.10^{-19}$Coulomb/electron

$Q \sim 4.8$ Coulomb is the total charge which has been dissipated in the soil.

This amount of charge is to be lost from the beam, to support approximately 5 min of existence of B.L. Therefore the total current of the virtual cathode for a 5 min interval is:

$$I_{cath.}=Q/\Delta t=1.6.10^{-2} \text{ A}$$

and the surface current density is

$$i_{cath}=I_{cath}/4D^2\pi=2.5.10^{-7} \text{ A/cm}^2$$

This is a very small value at the start of the normal glow region, and a reddish-orange continuous aura is expected, and it has been observed as well in this case.

If the ball diameter is smaller or the beam has high-energy electrons, a higher dissipation-scattering rate is expected, the surface current density will increase. Ionization channels will appear, and the aura distribution will be inhomogeneous. These channels will be like moving arms, spikes. As the aura is in the thermal boundary layer around the ball, where the temperature is high and the density is small, these ionisation channels will be quite diffuse, and they could move continuously.

Further increment of the surface current will yield a transition to an arc type of white halo, and it will give a characteristic hissing, crackling sound. The glow discharge is dim and noisless, the arc is bright and noisy.

e) Electric and magnetic effects

Perhaps the most important, but so far unrecognized feature of B.L. is its electric and magnetic properties. The B.L. has definitely negative electric charge, contrary to the assumption of Keul [6]. The effect of scattered electrons is clearly observable during its existence and after its explosion. The scattered electrons melt electric fuses, wires. Such cases have been collected in appendix B. The lack of the recognition of the importance of these effects paralysed the efforts to understand the real physical nature of ball lightning.

In the Habasovsk case, when a significant part of the beam electrons were dissipated by the soil, quite a significant charge (~ 5 Coulomb) accumulated in a short time. This charge had to leave the soil almost as suddenly as it appeared in the ground, due to Coulomb-forces, and it scattered through the ambient. Part of the electrons were collected by the neighbouring wires, other parts of them were moved back to the 4th D by Lorentz-forces. This process can be calculated by multidimensional random walking simulation, like the 4D Monte Carlo method.

The scattered beam electrons, which moved near the grounded wires around the impact site, were collected by the wire due to the potential difference, and some of them might have returned from the 4th D as well. The beam instability and the consequent blow-up added further electrons to this flow, causing a temporary overload to the wiring. This phenomenon caused the damage of wires around the site of impact observed by Dimitriev et al. [8].

This expanding charge cloud causes a prickling feeling, if the observer is near to the impact site. [3], [2].

The behaviour of B.L. around conducting and insulating materials can be explained simply. Around the B.L. sphere there will be negative charge distribution. If there is a grounded conductor near the B.L., this negative charge will induce charge separation in the conductor, thus attracting it. When the conductor is not grounded, the charge separation and attraction still occurs, but the conductor will have a negative charge very soon, it will repel the B.L. Obviously the beam as a whole will move, and not only the ball, its visible section in 3D.

In the case of non-conducting objects repulsion will be the dominating effect, because the charge leaving the beam will not leave the impact site as easily as in the case of grounded conductors.

The beam will penetrate into a solid object only if strong ambient electromagnetic field, lightning or the field of accumulated electrons guides it, or if a small object is thrown into the beam.

The balance between the charge transport capability of the ambient and the "charge production rate" will determine the B.L. movement.

It is well known that B.L. often enters rooms through small openings and ducts, like chimney. This is due to the potential distribution around a building (See Fig.5a) where the greatest potential difference will be around sharp, pointed objects. Consequently the beam electrons will be driven towards these places.

In the case of a slit on a non-conductive wall, the scattered beam electrons will cover the wall after a while, except the slit surface. The resultant potential distribution will "guide" the beam inside, where the potential is lower. (See Fig.5b)

After a while the situation will be the reverse: when the B.L. has spent some time inside a room, the local potential could be higher than outside, and the B.L. (the beam electrons) is forced out, through the same or via another opening, or it may burn its way out.

Previous considerations showed that the beam current is very strong, so magnetic effects are expected to happen around the B.L.

However, when the current is orthogonal to the observer's space, the magnetic effects are undetectable. (An experimenter living in a 2D plane will not detect the presence of magnetic field, if the field is created by a conductor perpendicular to the plane. The details of this effect are discussed in [24].

When the beam is not orthogonal to our 3D space, a magnetic field will be detected around it. That is, only an ellipsoidal B.L. will have a detectable magnetic field, as observed in [1] p 40, and [7].

f) Rotation

The sphere is a source of continuous outward flow of electrons. They move in radial direction in the magnetic field of the Earth. Thus Lorentz-forces will rotate the sphere, and the angular velocity is determined by the current density distribution. The local magnetic inclination angle will be parallel to the rotation axis of a spherical B.L. In the case of ellipsoidal B.L. the self-field will determine the rotation axis. [13].

g) Appearance in closed space

It is a natural consequence of the 4D beam model that B.L. might appear in any closed space, cage, irrespective of its material [2],[11].

It will move easily through narrow slits, if a strong potential difference exists between outer and internal space. The B.L. tends to enter a room through an opening, because building internals are on ground potential, and leave it after some surplus charge has accumulated there, and consequently repulsive forces arise.

When a beam is blown up, the electrons coming from the 4th D might penetrate into any closed room, [14] or closed metal Faraday cage (See the second case study).

h) The colour of ball lightning

The colour of B.L. is a consequence of electron beam impact upon rarified, ionised, high-velocity air atoms. The same phenomenon occurs in high altitudes around the magnetic poles of the Earth, termed as aurora, and air glow, and night glow. [25].

It is important to note that there are basic differences between the spectroscopic phenomena of solid objects and rarefied gases. In the latter case some transitions happen, which do not take place in the former one. These are the so called forbidden transitions, and some of them are responsible for the glow radiation of different colours.

Spectroscopy analysis of B.L. radiation has not been performed, but the physical circumstances are practically the same, therefore the same phenomenon must take place.

The air density is about the same in both cases only the electron beam density is higher for B.L. by several orders of magnitude.

The colour observations are inappropriate for energy estimations, but some important conclusions can be drawn:

1.) The usual energy range of aurora phenomena is in the order of 50-100 keV, that is, the minimum beam electron energy is in this region.
2.) If the B.L. has a specific colour, the beam is likely to be monoenergetic, "cold".
3.) When the B.L. (not the halo around the B.L.!) is white, the beam is most probably hot, its energy distribution is not uniform.

The same colours, which were reported in B.L. observations, were reported in polar aurora, and analysed as well.

The radiation intensity of the aurora depends on the gas density. There is an optimum value for the gas density, where the intensity is the highest. As the density is in strong correlation with the beam energy, an intensity estimation could help energy estimation.

For example, high intensity beams cause intense red radiation in low density plasma, that is, a red-orange B.L. most likely has a high energy. But similar colours may appear in low-energy interactions as well, therefore colour alone is not the safest mean of energy estimation.

The most important spectrum lines are that of N_2, O, O_2 and N in the aurora, and for B.L. the ionised states are the most interesting.

The long list of possible transitions will not be recapitulated here, but only the most important ones, like red oxigen doublet of 6300, 6363 Å, 5570 Å green, 2972 Å blue, or for N_2 3914 Å blue, etc.

The combination of these wavelengths could lead to a rich variety of colours.

Most observers report red and white colours, while blue is quite rare. It must be noted that the visual observation of blue colour compared to red or white is much worse due to scattering on air molecules. Thus beyond a critical distance the red B.L. will be visible, but not the blue one.

Second case study

The energy content of the above case was rather the exception, and not the rule. It was by far the best documented of B.L. observations, and it was indeed a very fortunate case.

Now an other case will be simulated, which has been reported in Singer's book [1] pp 39.

An LI-2 propeller driven transport plane (DC-3 Dakota Licence) was struck by ball lightning while flying at 3300 m.

"An orange red ball, 25-31 cm in diameter approached the front very rapidly from the front. When it was 30-40 cm from the front, it swerwed to the left, and passed by the cockpit. As it did so, it hit the propeller in the upper part of its arc and exploded. There was a blinding white flash, and a loud explosion was heard over the engine nose. A flaming stream passed along the port side of the body of the airplane, and the aircraft rose sharply. Strong radio interference had been noted, and when the radio operator tried to disconnect the antenna after the lightning discharge, he received an electric shock.

The only damage to the aircraft was in a small region of the propeller blade, the <u>trailing edge</u> having been <u>melted</u> over an area 40 mm in length x 5-10 mm in width at a distance of 30 mm from the tip."

As the LI-2 has a 3 blade propeller made of Al-Cu-Mg alloy, some order of magnitude calculations are possible. the propeller diameter is 3.4 m, n=930/m, the vertical blade vlocity is $\sim$280 m/sec (Mach $\sim$0.78). The air density is $\rho \approx 0.98$ kg/m^3 at 3300 m. The blade thickness at the impact area is between 1.2-3.1 mm. These are the available data for the calculations. The horizontal velocity of the B.L. is uncertain, therefore it is taken as zero.

The transition time while the trailing edge was exposed to the beam is calculated from the ratio of maximum damage depth/blade velocity.

$$t=10^{-2}\ \text{m}/280\ \text{m/sec}=3.6.10^{-5}\ \text{sec.}$$

It is quite possible that the blade has been exposed on a larger area than the actual damage, but as the horizontal velocity has been neglected, which shortens the contact period, this value seems to be a good compromise.

If the B.L. were a plasma blob, its temperature should be $\sim 5.10^9$ °K to melt the blade to the depth of 1 mm during the estimated period. For a 2 mm depth melting - $T \sim 10^{15}$ °K, and the 3 mm depth $T > 10^{15}$ °K is necessary.

The following damage mechanism requires the smallest energy:

The blade is heated by the REB up to the softening temperature of $\sim$400 °C (the melting is around 520 °C), then the impact area has a $\sim$4 % extention. The pressure arising from the expansion plus the centrifugal forces remove the heated and thus softer part of the blade, while the remaining surface is melted partially.

That is, only a limited heating is assumed, the blade will not be heated to the melting point.

The heat flux increasing the blade temperature is calculated as follows:

$$\dot{q}'' = mc\Delta T/t \approx 9.10^6 \ W/cm^2$$

Obviously, this is about the minimum heat flux which can cause this damage. A beam of higher energy would cause the same type of damage.

The beam electrons had to penetrate through the max. 3 mm thick blade in order to heat it in the full volume.

Therefore a 3 mm penetration depth is taken, that is, the beam has ~1.5-2 MeV electrons.

As Brehmstrahlung is negligible at this energy level,

$$P = \dot{q}'' = \mathcal{E}_{beam} \cdot \dot{\varphi}$$

The $\dot{\varphi}$ electron flux will be $\sim 2.10^{19}$ electrons/sec m^2. Therefore the current density is $\sim 3 \ A/cm^2$. In the case of a 30 cm diameter beam, the total current is ~ 2000 A. This is the minimum beam current, but the real value could have been higher.

It seems to be very likely that the beam was just above the threshold level, and blew up when the blade absorbed part of the beam current.

The beam explosion threw part of the beam electrons inside the fuselage, some of them were collected by the body of the crew. When the radio operator touched the antenna, this surplus charge left his body, causing an electric shock. he electrons scattered in 3D had less chance to penetrate through the air and the side sheet of the fuselage.

The white flash was the result of the partial melting of the blade surface in the REB.

There is one observation which could be interpreted as the direct consequence of the fourth space dimension.

T.Neugebauer [26] quotes the case (without reference) where a B.L. appeared in a restaurant and during its short lifetime a gold bracelet disappeared from a lady's wrist.

The most likely explanation is the following: The lady's body had strong electric charge, thus a sudden movement of the hand combined with the 4th D magnetic field simply lifted off the bracelet. It wound up somewhere else after the B.L. vanished. Such an effect might have happened on other occasions as well with other, less expensive objects, therefore nobody has paid any attention.

While most properties of B.L. can be explained by the 4D - REB model, a number of issues remain unsolved.

Unsolved problems

While it is relatively easy to prove that the B.L. cannot be explained by any three space dimensional model - if conservation laws are to be obeyed - obviously a number of fundamental problem is raised.

If space is four dimensional, the field of a charge should decay as $1/r^3$ instead of as $1/r^2$. Is it possible to resolve this contradiction? The concept of the charge has always been a source of problem. The multidimensional approach might help in the understanding of the fundamental relation between gravity, electromagnetic field, and electric charge.

The multidimensional model renders possible the understanding of the seemingly acasual appearance of B.L., which occurs in about 10 % of the observations.

There are about half a dozen observations which are even stranger; a B.L. disappears when it is hit by an ordinary streak lightning. Is it a streak lightning of positive ions? Or a strange reversal of causality in the multidimensional space? Or all of these observations were incorrect?

Causality might have seemingly strange features in a more than 3D space for a 3D observer. The study of "ordinary" B.L. phenomena might help to solve this issue.

In principle, the beam or ball diameter can be calculated if 4D electrodynamics is extended to relativistic, self-constricting space charged beams. This issue is although not easy if the plasma interaction and ambient geomagnetic field effects are added, but not very hard to grasp.

There is a less fundamental issue as well. Is it possible to formulate a more simple multidimensional B.L. model? The large diameter ring shape has been chosen in order to explain the temporal stability, the seemingly acasual appearance, and silent - explosive termination of B.L. The temporal stability definitely requires a closed form, so spiral-like open beams are unlikely. However, other closed forms are possible as well, but the ring has been selected due to its simplicity.

Experimental creation of ball lightning

All effects have failed so far to create B.L. experimentally. Powel and Finkelstein have created luminous plasma blobs with high frequency electromagnetic radiation, but the plasmoid didn't possess the observed properties of B.L.

According to the multidimensional model B.L. cannot be created in laboratory in the usual sense. Two remote sites are necessary, far from each other. (See Appendix C)

In the first site a very strong magnetic force field is to be generated in a pulsed (~0.1 sec) manner. Recently up to 100 Tesla can be generated in this way (but only for small volumes).

On the second site a pulsed electronic charge is to be accelerated simultaneously with the first one, the electron velocities are to be parallel to the 3D magnetic field. Recent techniques, using Marx generators, allow the generation of $\sim 10^6$ Joule, $\sim 10^6$ MW, $\sim 10^5$ A pulses.

In principle these could satisfy the requirement for a small, short life B.L.

The existence of an additional space dimension can be tested experimentally in a relatively simple way described in appendix C. Apart from these, some new and strange effects are expected to appear as well:

- In the multidimensional electromagnetic field the solid objects may change their crystal structure, and may form an instable and temporary crystal structure. (See Appendix B and D).
- Consequently, electric conduction, magnetic properties and the shape of the objects may change.

Keeping in mind these, such an experiment might be interesting not only for cosmologists, but for solid-state physicists as well.

Concluding remarks

Summing up briefly the formation mechanism and major features of BL, the most important point is that it can be created only in a four-space dimensional universe, where matter is distributed only in a 3D space, curved by gravity. Outside of this stable 3D subspace there is no stable formation of particles with restmass greater than zero. The fourth space dimension is not folded- or at least its radius is definitely larger from that of the electron.

The simplified formation mechanism is usually the following:

a) A powerful streak lightning accelerates electrons, and due to the fourth-dimensional components of the magnetic field generated by the lightning, those of them having the greatest velocity will be lifted to the "empty" fourth space dimension.
b) The accumlated (3D) electrons at the streak lightning impact site will further accelerate these electrons and they form a stable space charged beam due to inward fields contracting magnetic field.
c) This beam will have a circular, closed shape due to the circular movement of electrons in the geomagnetic field of the Earth.
d) This 4D ring will penetrate the stable 3D space at two locations:
   1) at the site of the formation, from a streak lightning impact
   2) at the opposite end of the ring diameter, (second penetration site). At this place, there is no need to have lightning to uaise the appearence of BL. Therefore it may appear in closed space, or in clear, storm-free weather.

Major formation criteria:

a) The beam current must exceed a certain threshold value, I critical, in order to overcame the repelling Coulomb forces, and to stabilise the beam. Therefore the potential difference and the net charge of the inducing streak lightning must be exceptionally large.
b) The length of the streak lightning from the source to the impact site should be as long as possible, in order to appear the effect of curved space.
c) At the impact site of the streak lightning charge accumlation should occur, therefore the target material should not be well grounded, or electrically insulating.
d) There should be no solid object at the second pentration site, because it will absorb the beam energy

All these criteria are to be met simultaneously. The temporal stability is increased if the beam is orthogonal to the 3D space, or as close to orthogonal as possible. As all this criteria are seldom met simultaneously, the rarity of BL is eary to understand.

The question naturally arises, why the BL is the only phenomanon, which requires multidimensional explanation? In the inaminate world, the multi-mensional properties of the space time manifold become significant only if large distances, strong field and freely movable electrons are involved. These come together only in case of atmospheric electric phenomena. (This is the reason why some of the observations were published in meteorology journals.) Therefore BL can't be produced in the usual lab circumstances, where the distances are small. the only exception could be a large particle accelerator during sotrm, but there the strength of the local magnetic field exceed that of the remote field. Magnetic fields of the accelerators are designed to keep the particle in a regular path with an-increasing field. So even the accidental chance of particle disappearance is ruled out.

Major consequences of the multidimensinal beam model:

a) The shape of the 4D beam penetration through the 3D subspace will be spherical, or ellipsoidal.
b) The movement of the beam - or its visible part, the BL - is governed by electromagnetic fields.
c) The impact site will be a source of continous electron emission, due to scattering, and this will cause the appearance of the halo, ionisation channels, sparks, crackling sound, etc.
d) The beam (BL) is stable as long as its current exceeds the critical level, then it will explode emitting all of the remaining beam electrons.
e) The amount of energy released at the penetration sites for a given beam is proportional with the target density and Z.
f) The colour of the BL is the consequence of plasma excitation phenomena in

rarefild gases by electrons, and the same phenomena takes place in the aurora. While on one hand it is important to prove that the BL can be explained in the above way, it must be proved that it can't be described by a 3D model. At first it must be noted that BL has not been created in the laboratory, despite consecutive attempts. Luminous plasma has been created, but allways in confined tubes, never in the free atmosphere. None of the characteristic BL features were observed, like aura, spark emission, regular shape, self sustained existence.

There are two major groups of 3D theories for BL, depending upon the assumed energy source.

a) <u>External energy source, from streak lightnings</u> through short wave EM radiation (Kapitsa, 1957). The following problems appear with this model:

1) The EM radiation from the lightnings should be continous, focused, and at the same wave length, while none of this criteria is met.

2) The BL plasma should be electrically neutral, while observations strongly suggest continous electron emission.

3) Electrically conductive objects would be heated by the eddy currents induced by EM wawes, but electrically insulating ones not. Observations clearly show that BL heats everything, regardless its conductivity.

4) The presence of such strong inducing EM fields have never been observed in nature.

b) <u>Internal energy source plasma sphere models</u>
None of the several models are able to account for the major properties of BL, not to mention its formation. There are severalcontradictions in the behaviour of BL if it is to be explained in this manner.

1) The spherical shape is explained by surface tension-altough the very concept of surface is not interpreted for a gas. Nevertheless in jet propulsion, plasma MHD and fusion research surface tension effects never appeared.

2) The density of the plasma should be equal to that of the ambient air, and BL ought to be driven by air-which contradict observations.

3) The occasional powerful energy release can't be explained by chemical interactions, because the energy density is higher than that of the explosive chemicals. Further on, energy transfer between a plasma sphere and a solid object results much slower, and different interactions than in BL interactions.

4) The usual features like halo, crackling sound, etc. are not accounted for in these models, neither appearance in closed space and lightning-free environment, and high altitudes.

5) Chemical energy producing reactions take place only in combustible gases, but not in air. These reactions yield small energy production and very quick reactions. They cannot account for the spatial and temporal stability of the BL.

6) Experiments with plasma never indicated the formation of stable, self-sustaining spheres. On the contrary, plasma is noted about its rapid recombination after the external energy source is turned off. The recombination takes place within milliseconds, regardless to the heating method.

A lage number of entirely different models were proposed so far to describe the properties and formation of ball lightning. These was only one common feature in all of them - the three space dimensional paradigm - which is so unquestionable, so natural for most of the researchers. Even those, who work in the area of multidimensional space models think about it usually as a necessary mathematical abstraction, not as physical reality. The ball lightning, this curious, rare natural phenomena might lead to a change in our wiew about nature.

To study the behaviour of BL will help in the understanding of a fundamental issue: the structure of space-time. The BL is definitely more than meets the eye; it should be in the mainstream of physics instead of a nearly forgotten curiosity.

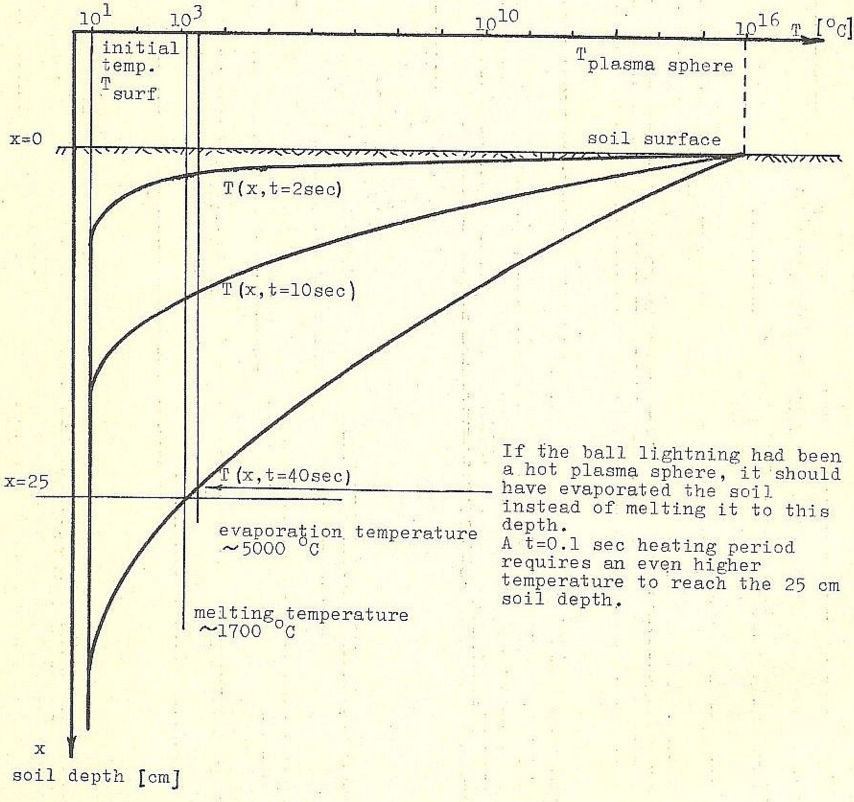
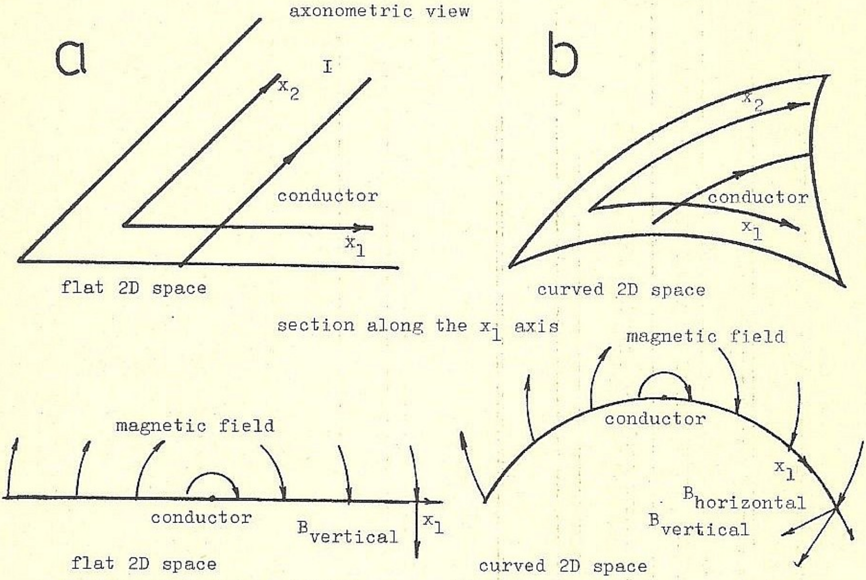


Figure 1. Temperature distribution in the soil as a function of depth and time if the energy is transported by heat conduction

If B.L. is to be explained as a plasma sphere, the high temperature is the first problem to be explained. The second problem is that the melting and evaporation temperatures are relatively near to each other. As there is no heat conduction above the evaporation threshold, simply because the material is evaporating, the conductive heating from plasma blob is ruled out. In every observation the energy transfer has the same feature: it cannot be explained with heat conduction or with heat radiation from a plasma blob.



The magnetic field is always vertical regardless of the distance from the conductor. The qualitative outcome of an experiment will not change far from the conductor.

The magnetic field is practically vertical to the surface near the conductor, however, moving away from the conductor the situation will change: a horizontal component will appear gradually. The qualitative outcome of an experiment will change far from the conductor.

Figure 2. Simplified 2D analogy of the magnetic field around a linear conductor in a flat and curved space

While case a/ is really a 2D problem, case b/ can only be at best approximated that way. If the distances are long compared to the space curvature, a 3D description is to be used for the curved 2D space.

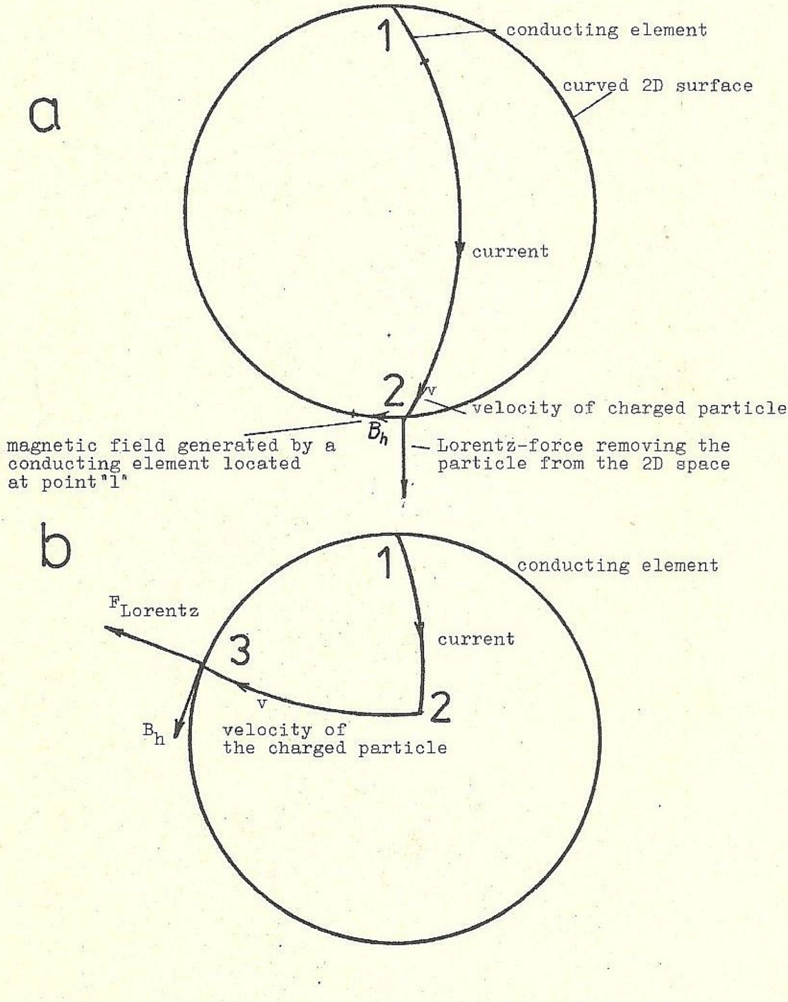


Figure 3. Simplified 2D curved space analogy of charge removal
In the case b/ only the horizontal component of the magnetic field is shown.

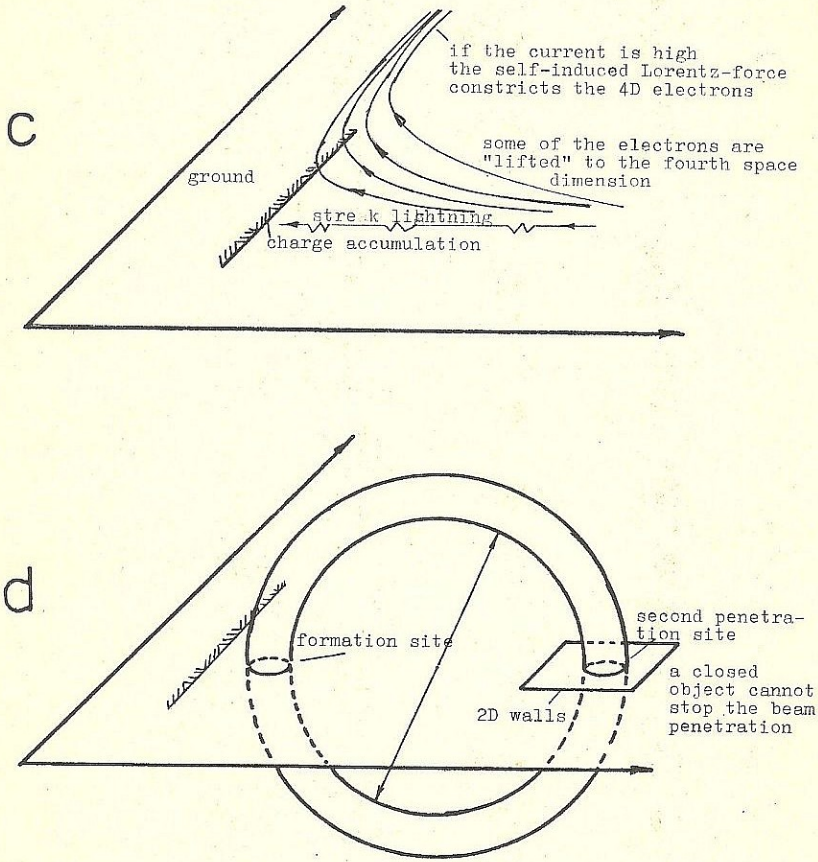
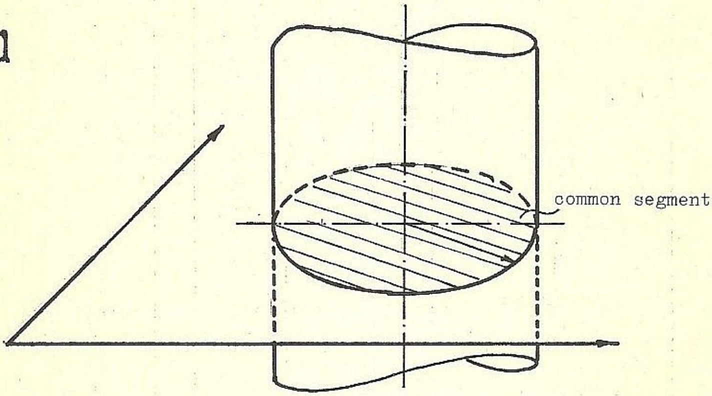


Figure 3 The 2D analogy of the formation and the geometry of B.L.

c/ Temporary charge accumulation at the streak-lightning impact site re-accelerates 4D electrons.

d/ The geometrical form of the ring-shaped beam. The ring diameter is significantly greater than the beam diameter.

a



b

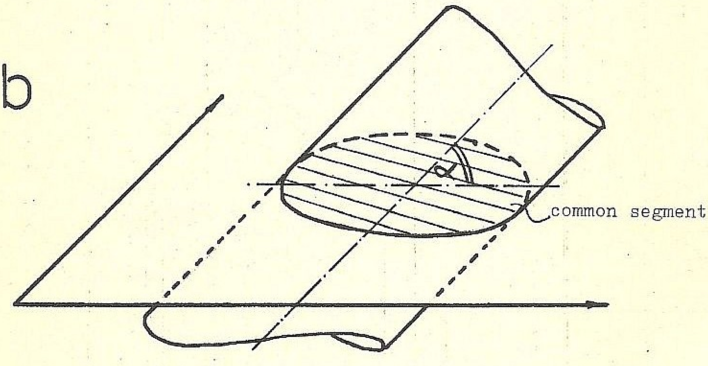


Figure 4. 2D analogy of beam penetration

a/ The segment of a 3D cylinder and a 2D space is a circle if they are perpendicular to each other.
If the cylinder is 4D and the space is 3D, their segment is a sphere.

b/ The segment of a 3D cylinder and a 2D space is an ellipsis if the inclination angle is $0 < \alpha < \pi/2$.
The inclination angle can be calculated from the ratio of the ellipsis axes.
(If the cylinder is 4D and the space is 3D, their segment is an ellipsoid. The inclination angle can be calculated from the ratio of the longer and shorter axes.)

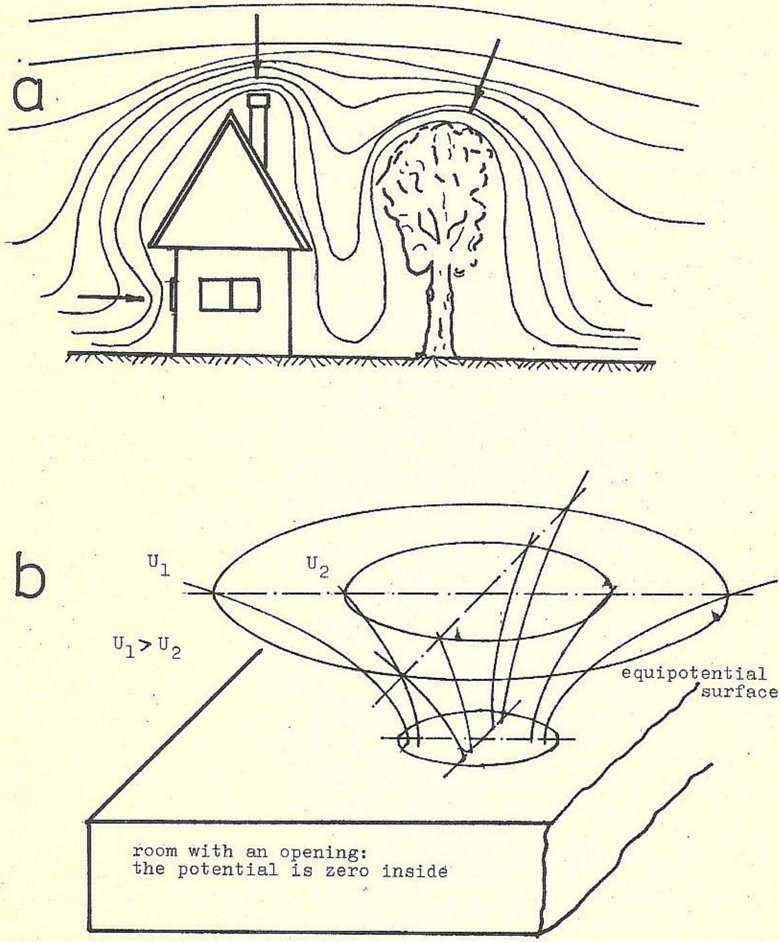


Figure 5. Electric potential distribution around a building a) and a hole b)

a/ The electrons, the beam, move towards the high-gradient locations as chimney, window or tree.

b/ The electrons, the beam, move into the hole where the potential is the lowest (ground potential).

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Appendix A

Stability of self constricted beam in vacuum and matter

The stable propagation of electron beams without external or self-induced fields is not possible, the beam will diverge due to Coulomb-forces. If the beam has relativistic velocity, the invard Lorentz-force will stabilize the propagation, due to self-field generation. (Lawson, 1958).

Mathematically $\frac{d^2 r_b}{dz} = 0$ if $\frac{\nu}{\gamma} \geq 1$ is fulfilled,

where $\nu = N \frac{e^2}{mc^2}$

and $\gamma = 1+2 \frac{eV}{mc^2}$

That is, the stability is a function of space charge density/ unit beam length, and the particle energy.

The existence of stable beams has been experimentally proven [27].

There are several means for the propagation of REB with arbitrary high current [29] although not all of them are practically feasible.

The beam propagation has to be examined with its interaction with neutral/ionised gas, plasma, or occasionally with liquid or solid target material.

If the beam has to pass through neutral gas, it will rapidly ionise the gas, thus loosing some of its energy. The ionisation will cause charge neutralisation very rapidly in intense REB. Prior to charge neutralisation, the beam could diverge, that is, different stability criterion is applied for beams in vacuum.

That is, $\frac{d^2 r}{dz^2} = 2 \frac{\nu}{\gamma} \frac{r}{r_b^2} \frac{1-fe-\beta^2}{\beta^2}$ where

$$fe = \frac{n_{ion}}{e_{electron}}$$

Therefore, the degree of ionisation is crucial to stability. The fe depends on the parameters of the given gas, as pressure, density, temperature, gas conductivity.

Consequently, the same beam could be instable for a different set of gas parameters.

Due to the multitude of essential parameters, the stability criterion cannot be stated simply.

The beam front propagation stability requires the introduction of an additional parameter, the magnetic neutralisation term. This parameter describes the destabilizing effect of the electric field induced by the current of the beam front. (As B.L. can be described as a practically steady state phenomenon, this effect is negligible apart from a very brief initial pariod. However, if this stability criterion is not met at the very beginning, the B.L. cannot be formed).

So it is possible to have stable REB under different conditions as shown on the next table:

propagation conditions	$\frac{\nu}{\gamma}$	f_{elect}	f_{magn}
in vacuum	1	0	0
in ionised gas, steady condition	1	1	0
in neutral gas, initial stage	1	1	1

The same conditions could be used for REB propagation in liquid, because the liquid will evaporate and be ionised, provided the beam energy dissipation is enough for the continuous energy supply, so $P_{liq} < P_{sat}(T_{vapor})$.

Appendix B

Qualitative case studies

Source: Singer /1/, p40,41.

Case description	Analysis
An airplane encountered a B.L., diameter 10 cm. On the fuselage the hemispherical (9 mm diameter, 2 mm maximum thickness) rivet heads were melted.	The B.L. was attracted to the airplane, due to electrostatic charge influence. The electric force field was the strongest at the rivet heads, therefore the B.L., (the beam, touched them, yielding melting and evaporation.
The rivets were arranged in two rows. A shower of sparks appeared. The cabin was strongly magnetized, causing a 100^o error in the compass. The radio was operating, but the radiocompass was incorrect.	When a rivet head was evaporated, the electric field lead the B.L. to a new rivet head. The process was continued until the plane fuselage became negatively charged, thus repulsing the B.L.
The shell of the fuselage remained unharmed.	The B.L. could have been ellipsoidal, causing magnetisation in the instrumentation, or multidimensional recristallization took place.

Source: Singer [1], pp37.

A dull red, pear shaped	The beam cross section was irregular, due to the absorption of positive ions.
B.L. appeared in a closed room, of 2 ft. thick walls.	4D beam passing through a 3D room, at the second penetration site.
Short, red streamers flared out from it in all directions.	Due to collisions with air atoms, beam electrons are lost, forming aura around the B.L. At certain points local electron streamers are formed, where the local ionisation rate is higher than the average, these ionisation channels emit light, and they are visible.
It left the room, over the top of a truck, exploded about 1 m above the ground.	The electrons filled the room, thus the Coulomb force pushed out the B.L. The scattered electrons charged the truck and as there were no sharp projections on the top, it repulsed the B.L. At a critical energy loss, the beam exploded.
Circuit breakers were tripped and fire started where the wires were within a few inches from the B.L.	Part of the scattered electrons were collected by the wiring, the sudden overload of current overheated and melted the breaker, and the current overheated the wiring, causing fire.

Source: Barry [5] pp 47.

Case description	Analysis
A red ball lightning, diameter 10 cm descended from the sky	Most probably high energy B.L. created by a forked streak lightning. It moved downward, because the Earth surface is on a smaller potential.
Struck a house, cutting a telephone wire	The wire was thin, therefore a high gradient electric field was created by charge influence. The B.L. was attracted, as it couldn't charge the wire, being grounded, it melted it.
The B.L. burned a window frame	Some sharp metal part, perhaps a nail or a knob was there. After charging them, the B.L. was repulsed.
It came to a barrel, filled with water of about 4 gallons.	The B.L. approached the barrel being on the smallest potential, so the beam heated the water.
The dissipated energy in the water was about 3.10 Joule, but mass loss due to evaporation was not estimated, due to lack of data.	The water boiled and evaporated, thus overheating the vapor, and ionising it. The estimated value is a pessimistic calculation, Brehmumstrahlung has not been considered, neither mass loss due to evaporation.

Source: [6], pp 136.
(case 44)

A blue 40 cm B.L. appeared, without lightning.	The beam has been observed at the second penetration site.
The borders of the ball were blurred.	Beam had no sharp edge, contour.
After an explosion the ball disintegrated, and tickling sensation, like from static electricity, was felt.	The beam became instable after a while, then exploded. Part of the electrons, scattered around caused the tickling sensation of the observers.

(case 64)

Lightning struck a lake, an ellipsoid, luminous form, like a discus formed at the impact.	Streak lightning turned into ball lightning, and the beam was not perpendicular to our 3D space.
Its dazzling core had about a 1 m diameter, the blurred edges were 2-3 m across.	Edges were blurred, because the ion temperature was less there due to a high local surface/volume value. The inclination angle has been about 30^o to the 3D space from the 4thD. (Assuming 1 m beam diameter and 2 m ellipsoid length.)

Case description	Analysis
(case 43)	
15 cm diameter B.L. fell in a storm to the ground, (behind a power line)	Formation unspecified, perhaps the power line had a role
It fell into 3 identical balls, glowing pieces spurted backwards from the top of the balls.	Beam instability Sparks emitted from an ionization channel on the top of B.L.
Two balls rolled on the asphalt	The asphalt, being non conductive, repulsed the two B.L. with their own electrons, which formed a layer on the surface.
The third approached a wire fence and passed it without effect	The fence attracted the B.L., which had a low energy, thus the wire was not melted.
(case 15)	
A streak lightning stroke a building, destroying the wiring throwing out the electric meter of the wall, passing through a crack of the wall	The streak lightning was transformed into ball lightning with the help of wiring in the wall. Electric field of the accumulated charge forced the B.L. through a crack,
It bounced down on the steps like a ball, and disappeared in a grave mound.	emitted electrons formed a repulsing electron layer on the surface of the stone steps, the beam collapse has been initiated at the other penetration site.

<u>Source: Charman [2] pp 265</u>

Case description	Analysis
During heavy thunderstorm, lightning struck the roof of a metal hangar.	Streak lightning is formed into a B.L. with the help of conductor, changing the direction of the electrons.
A bluish, 12 cm diameter B.L.appeared moving in an erratic zig-zag	Electric field changed frequently and randomly in the thunderstorm, causing a zig-zag movement pattern.
The B.L. touched the ground with a loud crack.	Beam energy reached the critical limit, exploded.
An observer, standing about 3 m from the impact site, received a strong electric shock despite rubber soled boots.	Beam electrons after the blow, scattered by the air molecules caused the electric shock.

Case description	Analyses
pp 272.	
After a near flash to a house a B.L. appeared in a closed room like a fire-ball, giving a buzzing crackling noise, like an arc welder	The 4D beam passed through the room. Scattered electrons were leaving the arc-like noise
The B.L. flew near the observer, who covered his face, but no heat was felt.	A low energy B.L. passed near the observer, with negligible heat radiation.
The B.L. disappeared suddenly, there was no damage to the room.	The beam collapse took place at the other penetration site.

Source: O.A.Kolosovskij, Zh.Techn.Fiziki, Vol.51, N^{o}4, 1981. pp 856

Case description	Analyses
During a storm, a class of students noticed a 5 cm diameter, orange coloured B.L., floating outside of the windows. The B.L. was "hairy" all the time. It moved towards the closed glass window, and a hole appeared gradually on the window pane. It took about 1 sec to make a 3 cm diameter hole on the outer window pane, while the internal one was unharmed. The edges of the glass were red during the process. Soon it moved away, and exploded with a loud bang. The teacher, who held a slide projector in his hand, received an electric shock at the time of the detonation. The hole on the window pane has not been of uniform diameter: its outer diameter was larger by 1 mm than the internal one. The edges of the hole were not melted. The subsequent stress analysis showed no remanent mechanical stress. Similar holes have been produced by CO_2 laser radiation. Simulation experiments by (gas blowing) flame torches could not reproduce the same hole: the edges were always broken, even if the flame was restricted to a circular spot by a metal ring.	A small B.L. approached the window pane, and evaporated part of the glass. Due to the spherical shape of the 4D beam -3D space interaction, the outer diameter of the hole has been larger. As a consequence of glass evaporation there was no melted trace on the edges, but the scattered electrons heated it to some degree, therefore, the edges were red for a while. The scattered electrons were collected partly between the two window panes, therefore, the B.L. was repelled after a while, before it could penetrate through the window. The B.L. was "hairy" due to the ionisation channels. When the beam became unstable, it blew up, part of the electrons got to the classroom by penetrating through two window panes, other part of them came directly from the 4thD. Some of the electrons were collected by the teacher's body, and the electric shock was caused by their movement through the ground wire of the projector. The unsuccessful simulation experiments by plasma heating showed again that the B.L. is not a plasma sphere, only volumetric heating could cause such a trace. This is due to the low heat conduction coefficient and low tensile strength of the glass. Such a trace can't be produced by plasma of any temperature.

Source: Corliss, pp 70[4]

Case description	Analyses
Somewhat after a powerful lightning struck, an observer, sitting in a room, saw the paperlined frame covering the fireplace opening fell down, and a fireball of the size of a child's head appeared and gently wandered about the room at low level over the floor tiles. After carrying out a few moments in	A B.L. has been formed from a streak lightning, and it moved down through a chimney due to the low electric potential inside it. The covering of the fireplace has been blown off by the shock wave of the lightning. As no streamers on the B.L. surface are mentioned, the rate of beam electron

Case description	Analysis
different directions the ball lifted to the height of about 1 m, it became somewhat elongated, and made its way along a slanted path toward a hole about 1 m above the upper cornice of the fireplace. This hole accomodated the pipe of the stove, but it was covered with paper. The fireball went straight to this hole, pelled off the paper without tearing it, and ascended into the chimney. It climbed up very slowly to the mouth of the chimney which was about 20 m above the ground, and it produced a dreadful explosion, which destroyed part of the chimney, and hurled the broken pieces into the yard. The roofing of several smaller building caved in. The fireball did not radiate any noticeable heat, to follow conducting bodies, or to veer away from air currents. (First published in Comptes Rendus, 35:2-3, 1852)	scattering had to be low, that is, the ion density had to be low inside the impact volume as well. Consequently, the heat radiation had to be low as well. The conducting bodies were not grounded, so the B.L. was not attracted to them. After a while the room was filled by scattered electrons, the electric potential became higher inside than outside. The B.L. started to move towards the covered chimney opening, where the electric potential has been the lowest. It became slightly elliptical in the non-uniform electric field, this slightly increased the electron scattering rate. Scattered electrons moved towards the chimney hole as well, and part of them were stopped and stored on the covering paper and its periphery. The repulsion between the electrons on the paper and the wall peeled off the paper, before the B.L. got there. The beam had become unstable by the time the B.L. reached the mouth of the chimney, it blew of, but only a fraction of its energy was released in the form of mechanical energy of the shock wave; most of it heated the enviroment.

<u>Source: Stahanov[3]pp 89</u>

Case description	Analysis
During a storm, a white 20-30 cm diam. B.L. descended from the sky.	The B.L. has been formed in a cloud--cloud streak lightning.
It moved vertically to a garden tap, diameter 5-6 cm, height 70-80 cm from the ground. After the impact it melted the top part of the tube, the end became closed, melted iron drops were found, and the colour of the tube changed like the steel after hardening.	Due to charge separation, it moved towards the grounded, vertical metal tube. As the tube had been grounded, the B.L. was not repelled. It melted the upper part of the tube, closing it. The high temperature caused the change of colour.

<u>pp 30</u>

Case description	Analysis
A soldier was awakened by a shot from his own rifle under his head. After opening his eyes, he saw a small B.L. going around the room, then leaving it through the window. The rifle was melted on a small area, 5 mm diameter, and 3 mm deep. The metal evaporated from the small hemispherical crater. The soldier felt no heat during the events.	The B.L. has been attracted through charge separation towards the metal rifle. When the B.L. reached the rifle, evaporated a part of it, and heated it as well, causing the firing of a bullet. The impact crater was small, because the rifle has not been grounded, the scattered B.L. electrons charged the metal. The negative charge repelled the B.L. and the room has been filled with electrons as well. This space charge repelled the B.L. from the room as well.

Source: Stahanov

Case description	Analysis
pp 33	
2 B.L. jumped out of a stove their diameters being 10-15 cm. They moved from the kitchen through a corridor to a room. They approached the grounding wire in the wall, their shape became ellipsoidal near the wire, and they disappeared when they touched it. They emitted a crackling sound while they moved.	The B.L. most probably came through the chimney, and it was split by an ungrounded object. Filling the kitchen with scattered electrons, it moved to the adjacent corridor and then to the room. It was attracted by the grounded wire. The electric force field has been quite inhomogeneous around the wire, it distorted the beam cross-section. Thus the beam cross section became elongated. At the grounding wire the beam electrons were collected, and the beam collapsed. The corona discharge caused the crackling sound. The beam collapse has been initiated at the other penetration side, so the B.L. vanished without explosion.
pp 38	
A group consisting of 25 tourists observed a B.L. during a storm, in a forest. At first it was white and at the height of the tree tops. It became gradually yellow, then orange, later red. It gradually descended, continously spitting sparks and "materials". The pieces of material were visible for longer periods then the sparks. The B.L. became deep red at the end of its existence, and its interior was quite dark. The B.L. vanished silently near the ground. The B.L. was visible from only one point in the narrow path, so the tourists observed it one after the other, each for 5-6 seconds.	The B.L. must have been loaded with ions, that is, it was a "hot beam". The ions drifted towards the edge of the beam, and the ion cluster was periodically torn off when the centrifugal force overcame the Coulomb force. These clusters, leaving the beam, were seen as the "material". This ion ring, ion cluster was parallel to the 4D electron beam, but its diameter was less. The cluster collided with the air molecules, thus it produced visible light, but this periodic phenomenon had a shorter lifetime than the beam itself. However, its lifetime was longer than that of the sparks. The B.L. must have been pear shaped periodically, but it was quite far (about 25 m) to be observed carefully. When the penetration length became comparable to the B.L. diameter, the internal part became dark due to stronger energy dissipation in the centre than at the edge. The beam collapse has been initiated at the other penetration site, the explosion has been produced there.
pp 128	
During a storm, a streak lightning hit the ground. Drops of fire emerged from it, which in 5-7 sec formed a 50-70 cm diameter fall. It rose to about 2 m, and started to move horizontally.	After the hit of the streak lightning part of the electrons accumlated in the ground. The electrons of the streak lightning decelerated near the impact site, and the 4D Lorentz-force

Case description	Analysis
Arms protruded from its surface, its surface seemed to boil. A stone wall stood in its way, therefore the B.L. changed its course. As it moved away, it passed along a haystack, and ignited it.	removed them from the 3D space. Moving away from the impact site, the electrons were accelerated again. Reaching the current threshold, they formed a stable self contracting 4D R.E.B. The streak lighning consisted of several separate strokes, thus several small beams were formed at the start. The parallel ring currents attracted each other, thus the beams merged, formed a single beam. (4D ring current). The B.L.formed this way was repulsed from the ground surface, it lifted off. Corona discharge produced ionisation channels, "arms". Due to turbulent heat transfer at the surface, and large temperature gradients, the surface seemed to boil. The B.L. changed its course at the wall, because scattered beam electrons accumulated on its surface.
<u>pp 128</u>	
A streak lightning hit the surface of a lake, and a 10-20 cm diameter, orange B.L.emerged from the surface. It lifted to about 20-50 cm off from the lake surface, it moved horizontally, about 30 m. It suddenly sunk in the lake, a detonation was heard, and steam was visible above the surface.	Like in the previous case, streak lightning electrons were accumulated temporarily in the water. The electric field of the accumulated electrons at first decelerated the electrons of the downward streak, while the 4D Lorentz-force removed the electrons from the 3D space. Ring shaped electron beam was formed in the magnetic field of the Earth, and this ring had two intersections with the 3D space. In this case the formation site was observed. The beam would have moved towards the Earth surface due to its low electric potential, but scattered beam electrons accumulated on the surface prevented it, so the movement was horizontal.The direction of the movement was determined by local electric fields. A sudden electric flash in the nearby forced the beam into the lake, where the water evaporated in milliseconds and the beam passed through ionised M^+ and O^+ atoms. Outside of the impact sphere they recombined to form steam bubbles, which caused the sound effect. When the beam became instable, a large amount of energy was dissipated in the water.
<u>pp 127</u>	
A streak lightning hit the power line, not far from the mast. A B.L. was formed, it moved along the wire. It jumped to a lower wire, moved for a while, then split apart among the branches of a nearby tree.	The hit of the streak lightning heated the power line increasing its ohmic resistance. Temporary charge accumulation occured, B.L. was formed. The observer reported the B.L. at the formation site. It moved for a while along the wire, but it was overheated,

Case description	Analysis
It fell to the ground in small spheres, then they moved on the ground up and down. They emitted sparks continuously during their whole lifetime, about 10-20 sec. The B.L-s were extinguished silently.	ohmic resistance increased, the scattered electrons repelled the beam. The lower wire attracted the beam due to charge separation, but after a while the same phenomenon was repeated. The branches of a nearby tree became charged by scattered electrons, and the beam was splitted. Positive ions were absorbed from the ambient air during the whole process, so the beam maintained stability after the split. The small B.L-s extinguished silently due to charge compensation by the positive ions. The spark emission was a consequence of scattered beam electrons. The beam became unstable at the other penetration site.
<u>pp 98</u>	
During a heavy storm a person entered a room. He felt a sudden hit on the back of his head and lost consciousness for two weeks. Other observers sitting in the room reported that a small 5-7 cm diam B.L."jumped" from the socket of the lamp and moved towards the head of the injured person. At the same time, when the B.L. was observed, the thunder of a nearby streak lightning hit was heard.	The reported B.L. was observed at the second penetration site. The beam passed through a room being on overall ground potential. Within the room it passed near to the lamp socket, because it was attracted by it. After heating it the B.L. was repulsed and it moved towards the person just entering the room (he was probably wet as well). The beam electrons caused the shock and the faint. The electron beam-ring diameter must have been small, 5-6 kms, because the thunder was heard, and the B.L. diameter was small.
<u>pp 97</u>	
A 20 cm diameter B.L., jumped off from a telephone, it burned through a wall made of thin wood, it continued its movement by burning through two wooden doors, then it moved to the street.	A B.L. was observed at a second penetration site, it was created somewhere else. The electron beam governed by ambient fields moved through the wooden walls, burning a hole into them.
A 20 cm diameter B.L. jumped off from the socket of the wire broadcasting. It moved to the door of the stove, and it disappeared.	Similar case as above, except that the B.L. was attracted by the metal stove door.
<u>pp 130</u>	
A small, 5 cm diameter B.L. appeared on the tap of a heating radiator. It detached from it, moved to a pile of nails under the table. It jumped off from them, then returned again to them, and blew off in a small detonation.	It was a second penetration site, the B.L. moved to the nails due to charge separation. After charging them the beam was repelled, but the nails lost their charge soon due to peak effect, and attracted the beam again. The beam blew up when it became unstable, and the radiator collected the electrons.

Case description	Analysis
pp 107	
A B.L. appeared from the electric wire rolled to the table, fell to the leg of a person sitting at the table. The leg became red for several days, but no heat was felt during the contact.	The same as above, the redness on the skin was caused by the electrons, and soft X rays. The radiation dose was small, therefore it disappeared.
pp 119	
Two persons observed a B.L. moving through a hole on the window pane, from a distance of 10-15 cms. At first the B.L. took an ellipsoid shape, then elongated as long as it was so thin that its diameter was equal to that of the hole on the window. It cracked and oscillated continuously, from its surface 1.5 cm long rays hang out. At the end of these rays sparks appeared.	The electric potential difference forced the beam into the room. Around the hole the field of the electrons on the glass acted as a focusing lens, distorting the B.L., the beam shape. This was a temp rary phenomenon, it regained its shape when it passed through the obstacle. The rays were the ionisation channels caused by the scattered beam electrons in the hot thermal boundary layer. The electrons caused the sparking at the end of the rays, outside the thermal boundary layer.
pp 118	
A yellow, orange size B.L. was seen to pass through a small hole on the window. It looked as if it were flowing from one half to the other, (from the outer half to the inner half)	The same as above. Recombination is due not to surface tension, but to the equilibrium of electric and magnetic forces in the beam. A beam, which is not orthogonal to our 3D space, yielding an ellipsoidal B.L., would recombine again as ellipsoid after passing through an obstacle.

Source: W.R.Corliss: Handbook of unusual phenomena. Source book Project[4]

Case description	Analysis
pp 76	
After a sound of explosion a torpedo-shaped B.L. has been observed, 50 ft about the top of buildings. The sky was entirely clear overhead, and clouds were gathering. A downpour of rain followed about twenty minutes later. The B.L. was about 6 feet long and 8 inches in diameter, the shell or cover having a dark appearance with here and there issuing tongues of fire from spots on the surface resembling red hot unburnished copper. It moved slowly, and the covering seemed rupturing in places and thru these intensely red flames issued. When first seen it was surrounded by a halo of dim light, some 20 feet in diameter.	The B.L. was created far from the observation site, 10-20 km away in a storm (a second penetration site has been observed). By the time the storm reached the observation site it dissipated most of its energy, therefore there were no lightnings. The beam inclination angle was small, therefore the ellipsoid was quite elongated. Due to this shape, the beam electron scattering was very intense. The B.L. was surrounded by a number of ionisation channels, (tongues of fire) and a dim halo. Its lifetime was relatively short, due to the continuous heavy electron loss. It appeared with an explosive sound because when the beam penetrated through the air at first, it heated the air very rapidly. When the beam became unstable,

Case description	Analysis
It exploded with a deafening sound within 18- or 20 feet from the ground.	it disintegrated by a loud detanotion again, due to the sudden release of leftover beam energy.
Sorce: Corliss, pp 73	
An observer reported a bluish green 2 ft diameter B.L. laying around 1/4 inch diameter "strings of light". There was no rain, no sign of thunder. It remained at the feet of the observer for about 3 sec, then rose, cleared the houses some 20 ft , and landed at a distance of 1/4 mile. There was a loud explosion and much damage done to a house.	The B.L. was observed at the second penetration site, while it was created far away. The observer did not notice the actual formation of the ball at the second site. It stopped for a while near to the observer where he saw the ionisation channels. It moved further away, and exploded near a building damaging it by the release of the leftover beam energy.
Source: R.A.Leonov, pp 16,[7]	
During a storm, a reddish ~ 3 cm diameter, nut-size B.L. appeared from a clay stove, in a peasant's house. According to the observers, the B.L. made some random-like movement, then ascended to the desk slowly, towards a metal cooking pot, and the metal surgical instruments of a medical student, one of the observers. It hovered there for a while and then left the room via the open door. It approached a tree on the yard, its shape became ellipsoidal, and its colour became whitish when it reached the tree. An explosion was heard, and the tree was ignited. It burnt for a while, but the flames were soon extinquished by the rain. During the explosion day "electric sound was heard from the neighbouring houses as well. The medical student noticed, that his surgical instruments were magnetised, but it disappeared after a couple of days. The whole event took about one and a half minute.	The beam moved to the room due to its low potential. It moved towards the metal pot and the metal surgical instruments. These became magnetised but not by the usual and known magnetic domain rearrangement, but ostensibly by multidimensional recristallisation. This is a temporally unstable phenomenon because only 3D matter structures are stable. Consequently this phenomenon is temporary, and it has returned to its usual crystal structure after a while. This observation has been important, it shed light to this unstable, ostensibly multidimensional solid state physics phenomenon. Further features of the observation are the usual ones; near the more or less conducting tree in the strong electric field the B.L. became elongated. When it hit the tree the wood has been heated and ignited. The beam became ustable, and blew up, most of the electrons were scattered around the neighbourhood, and this caused some sparks. The sound of sparks was heard and noticed by the observers.
Source: R.A.Leonov, pp 21	
A B.L. flew to a kitchen through the open window. It approached a pot filled by water, it turned around and flew out to the street. It killed two men and a horse on the street, and melted a part of a railway rail.	This observation clearly reveals the difference of B.L. behaviour for grounded and ungrounded conductors. The pot was not grounded in the kitchen, therefore the B.L. has been repelled soon, when the scattered beam electrons charged the metal pot to its maximum capacity. The two men, the horse and the rail was grounded, they attracted the beam. People hit by B.L. are injured by the heat of the beam dissipation, but the lethal effect is caused usually

Case description	Analysis
	by the DC electric shock. This case clearly shows that it is better to avoid B.L., especially if the observer is in the open air. But touching the B.L. is very dangeous even indoors as well, due to the heat and X ray effect.
Source: R.A.Leonov pp 20	
A propeller-driven Il-12 encountered several B.L-s during a flight from Irkutsk to Habarovsk. The small shiny spots near the cockpit window merged into a toroid-shape ring with a 1.5 m diameter and a 10 cm thickness. It grew for a while, and rotated quickly, clockwise. Its final thickness became about 20 cm, when it blew off with a loud detonation. There was no damage, only the paint was burned on the nose of the fuselage.	This is an interesting and unique observation. Several small beams united into a bigger one, and the usual sphere shape has been distorted by the conical shape of the fuselage. The metal body of the plane has been already charged by the electrons, so it repelled and distorted the beam. This case shows that the B.L. cannot be a plasma blob, because it would be blown away by the wind. The beam only partly ionizes the air, so relatively little energy is lost. When the beam exploded, the scattered electrons were repelled by the negatively charged fuselage, so only little damage has been done.
Source: V.V.Baliberdin, Samoljostoenie i tehnika vozducsnaja flote 1956.$N^{O}3$, pp 102	
A 30 cm diameter B.L., has been observed while it broke through the roof tiles, and melted a hole on the ceiling. It made a couple of circles in the room, then it left via the open door. When it was about 50 m from the house, it blew up with a powerful detonation. The shock wave destroyed a small hut made of sundried brick. Subsequent calculations revealed that the power of the shock wave has been six times more than that of a 30 cm diameter TNT sphere. Other types of chemical explosives would be equally inadequate to produce the same effect.	The beam, while penetrated through the ceiling, although lost some of its energy, remained stable. When it was in the room, scattered electrons were accumulated, and the resulting repulsion forced out the beam. (This is a general feature, it occurs frequently). When the B.L. (the beam) moved off the house, it became unstable, due to the loss of electrons. The Coulomb forces in the beam exceeded the self constricting Lorentz force, thus the stability criteria was not met. The beam electrons were released, and scattered around the impact site. Their energy was turned partly to the ionisation and heating of the air, which produced the shock wave. Other part of their energy was transformed into brehmstrahlung.
Source: R.A.Leonov, pp 20	
An IL-12 type propeller driven airplane flew at a height of 4000 m, where there is no intensive lightning activity. A red-orange coloured ball lightning was noticed by the pilots, and it hit the right hand side engine. A detonation shoock the plane, but the engines worked continuously. All the electronic equipment, radio receiver and radicom-	The electric phenomenon is the most interesting in this observation. The temporary malfunction of the electronic equipment could be a consequence of two different reasons: a) 4D scattered electrons blocked the proper functioning in the amplifiers and condensers, b) Electrically insulating materials became temporary conductors, thus the

Case description	Analysis
pass ceased to function. However, after a while they started to function properly again, without any mending. After the landing, the check-up showed melted spots on the propeller blades.	proper functioning became impossible. The malfunction of electronic equipment is a usual feature of B.L. observations, and it cannot be the consequence of 3D scattered electrons, because the airplane is a 3D Faraday cage.

Source: J.R.Powel and D.Finkelstein: Ball Lightning American Scentist Vol. 58, pp 262 280. 1970.

pp 264

Case description	Analysis
A B.L fell from a tip of a funnel, attached to the storm cloud towards the ground and exploded when it hit. The trees looked for a short time like Christmas trees, as if they had candles at the tips of the twigs.	The beam became instable after reaching the ground and the beam collapsed at the observed site. The beam electrons scattered around and accumulated on the leaves of nearby trees. Due to the effect of sharp edges and tips of the leaves, the electrons left them at these places. (Electric wind and tip effect). This caused the visible bluish light, which is called StElmo's fire. A large amount of charge had to be scattered around to cause this effect.
A bluish-white, 30 cm B.L. appeared after a lightning stroke a tree. It had some discernible internal motion, and had a furry outline. It flew to an apartment of a nearby house through an open window. Then it moved to the adjacent room through the opening of a wooden screen. It moved horizontally in the room at a height of about 1.5 m, melted an almost circular hole 28 cm in diameter through a closed glass window, and exploded on the ground below. (Melting a hole in the glass requires tens of thousands of Joules).	The B.L. was created in the manner described earlier. The observer noted the internal motion in the plasma blob, due to turbulent effects, caused by the ionising, heating effect of the beam. The beam moved towards places of low potential. It was forced to leave the room through the window pane, evaporating it. (Molten glass drops were not reported or radial breaking of the window pane, thus its material has been evaporated). The beam became instable when it hit the ground, and exploded.

Source: Nature, Vol 260, pp 596, 1976.

Case description	Analysis
A 10 cm diameter bright blue-purple B.L. appeared in a kitchen during a storm. It was surrounded by a flame coloured halo. The B.L. moved towards the witness at the height of about 95 cm. The ball hit the observer below the belt, and burning heat was felt. A hole was produced on her dress, and tights, but her legs were not actually burnt but became red and numb. She brushed away the ball, and redness and swelling appeared on her palm, and it seemed that the gold wedding ring was burning into her finger.	The witness felt the heat only after the B.L. contacted her body. Her legs became red and numb due to soft X-ray radiation and the effect of scattered beam electrons. The electrically non-conducting skirt and tight became partially and locally effected, they evaporated. The legs were not in the "stream" of the beam, therefore the injury was only marginal. On the contrary her palm was burned, because it had a direct contact with the beam. The gold ring was the hottest,because of its high density and high Z. The B.L. was repelled because part of the beam electrons accumulated on the skin, and their repulsion made the beam move away. The physical features (halo, rattling sound, termination) were the

Case description	Analysis
	usual. It has to be noted that the gold ring should have protected the skin during that sudden hand movement, but it was very hot.

Source: Nikolai Zhiltsov: Mysteries of Ball Lightning, Zemlya i vselennaja

Case description	Analysis
An episode was reported by T.Vasilyeva from the village of Kolotychino near Moscow."At 10 o'clock in the morning on May 10, 1978, a thunderstorm broke out. As lightning struck a luminous lilac ball the size of a human head appeared on a light switch. In a moment the switch caught fire. I remember thinking that if the flames spread to the wall-paper our whole wooden house could burn down. I struck at the ball light and the switch with all my might and it immediately fell into a host of tiny balls which came down on the floor. Only then I was gripped by fear. My hand had been burned down to the bone and the skin on my fingers was charred".	This case is similar to the previous one, with a major difference. While in the former case the palm and the fingers were tangential to the ball, therefore a larger amount of electrons could accumulate on the hand, rendering possible a larger repulsive force, in this case the fingers were radial, and their velocity was ostensibly greater. The ball fell apart, because beam electrons were scattered and accumulated in the fingers, while heating it in the whole volume. The repulsive force of these electrons split the beam from inside into several smaller beams, which were stable for a while. The fact that the whole hand was burned instantly in the full volume indicates again the volumetric heating, not energy transfer through the surface. (A plasma blob could have damaged the skin, but not down to the bones). The physical features were the usual: the B.L. approached the switch due to the attraction of the ground wire.
The following case has been reported by navigator Valentin Akkuratov: "One February afternoon in 1946 our four-engine plane was on its way back from long-distance ice reconnaissance flight in the Arctic. The flight, at a height of 1.200 metres, was proceeding calmly. Suddenly, a blinding white ball flashed in the navigator's compartment.It smoothly moved along the left-hand wall in my direction, and stopped pulsating and swaying some 30-40 centimetres from my face. I didn't notice its heat but I did feel a light prickling in the upper part of my head. Then, changing its colour to greenish, the ball moved down and turned towards the hatch which led to the radio cabin. Rolling under the radio operator's seat, it exploded with a terrible roar. The seat's metal legs melted and a fire broke out. Luckily, the operator was unharmed. After we put out the fire I carefully examined the navigator's compartment. All portholes and hatches were tightly caulked and there was not a single chink. Meanwhile, the radio operator reported that the air was	The observed location has been the second penetration site. The navigator felt the light prickling in his head because part of the scattered beam electrons moved there. The seat legs might have been melted pior to the beam instability or during the beam explosion. The silence of the radio has been discussed earlier. The real curiosity of the case is that it happened in February, when the lightning activity is marginal. Note: If the B.L. had been supplied by radio frequency electromagnetic waves, both the navigator and the radio operator should have felt the heat - but they didn't feel it.

Case description	Analysis
clear and calm and there was no crackling in the earphones - a sure sign of an approaching thunderstorm."	
<u>Source: F.B.Mohr, Science, Vol.151, pp 34, 1966.</u>	
A basketball-size, bright B.L. with fuzzy edges appeared in a fiberglass screened patio in front of the witnesses. Thunder was heard at some distance of the observer's vicinity. None of the witnesses felt any heat from the ball. The B.L. moved to the floor and exploded. A neighbor's electric range was shorted out when the explosion took place. The witnesses were not damaged, and the whole event was over in seconds.	Second penetration site, and beam instability at the observed location. The electron range was shorted out by the electrons of the exploding beam. The source of these electrons was not the visible B.L., because the observers sitting in a closed room were not injured, but the expanding 4D beam. The room was more or less protected, because during the lifetime of the B.L. scattered beam electrons were accumulated there, and the expanding beam electrons were repelled.
<u>Source: Charman [5] pp.273</u>	
"Quite suddenly we (two witnesses) were aware of a large sphere (I think coloured blue and 60 cm in diameter) travelling very rapidly towards us. It struck the ground a few yars from us with a loud explosion. My parents inside the house, who had not seen the sphere, reported sparks coming from one or more electrical junction boxes".	This is the reverse of the previous case, a B.L., outside of a room, overloaded the electric wires inside a room. The electrons came from the exploding beam, and the electric wires collected them. There is no information wether doors and windows were open or closed. The subject did not reported electric shock, so most electrons were collected by the wiring.

This report concludes the qualitative case studies. It must be noted that only those reports were of interest where the B.L. had some interaction with its ambient, and the report contained some details as well. Unfortunately most reports are unusable, because the observers lost sight of the B.L., or nothing special happened, or important details were missing. Nevertheless, it can be shown that a large variety of different events can be deduced to a small number of basic phenomena, like beam stability, and electron scattering.

Appendix C

Possible means of experimental verification of the multidimensional formation mechanism

In principle there are several methods for the experimental verification of the previously described B.L. formation mechanism. There are two basic issues to be proven:

1) that the space time manifold contains at least four, locally non folded space dimensions, and matter is stable only in three of them;

2) In that structure a self-contracting 4D REB may exist temporarily and it will form a B.L. where it penetrates the stable subspace.

Obviously the first issue is of fundamental importance, while the second one is more or less a technical one. However, if B.L. can be formed artifically, a number of issues of high importance can be studied, ranging from multidimensional solid state physics to biology.

There are several possible experimental means to study the topology of the space time manifold, some of them will be briefly described here.

1) Verification of the temporary existence of electrons in the fourth space dimension.

There are two different ways to test the presence of electrons in the fourth space dimension.

a) Experimental verification of the electron transition to the 4thD. The procedure is similar to the B.L. formation mechanism, but much weaker electron currents are enough to produce the effect. It has to be verified that electrons leave the 3D sub-space as a consequence of a 4D magnetic field. (See Fig 1). Electrons should be accelerated in a linear accelerator, along the axis of a large conductor loop. In the case of a 3 space dimensional universe, the magnetic field of the loop would not influence the electrons, because the Lorentz force is zero, as the magnetic field and the electron velocity are parallel. But if the space is curved, and the magnetic field has fourth dimensional components, the resultant Lorentz force will lift off the electrons to the fourth D. The magnetic field must be far from the accelerator, in the order of several km-s, and the loop diameter and current must be substantial. There is an optimum distance between the loop and the beam electrons - at small distances the space is not curved enough for the effect to appear, on the other hand at long distances the magnetic field is too weak to produce the effect.

In order to plan such an experiment, a sort of unified field theory would be necessary to carry out the calculations.

However this experiment would be expensive, and without primary verification of this effect the risk will not be taken.

b) A financilly less expensive way to prove that electrons arrive from the fourth space dimension. That is, it has to be shown that the appearance of the electrons at a certain place can be explained only as the consequence of the electron impact from the 4thD.

As it has been discussed earlier, 4D Lorentz force removes part of the electrons from the 3D subspace, but usually the 4D beam is not formed, because at least one of the formation criteria is not met. Consequently the electrons in the 4th dimension repel each other, spread and return soon to the 3D as a result of attraction by positive ions, and Ehrenfest stability. However these electrons can be collected on a positively charged electrode, which is shielded from 3D electrons. The problem is the proper separation of the few 4D electrons from the large amount of 3D electrons. Such arrangements are shown in Fig.2.

A grounded conductor has to be distributed into sections, connected by rectifiers. It must be used as a lightning rod, but its outside surface is to be covered by thick electric insulator. The aim of the experiment is to prove that charge appears on the insulated electrodes after streak lightning impacts. The net current is to be measured. Special care is to be taken to distinguish this effect from that of the charge separation caused by a nearby streak lightning. The insulation must be thick enough to shield from cosmic radiation. The applicability of this solution depends largely on the reliability of the rectifiers and current meters.

An other possibility is to use small capacitors connected in a series, where a small amount of charge causes a measurable change in the voltage between the electrodes. Here the dielectric between the electrodes ought to be a very good insulating material, and the voltmeter has to have a high input impedance to eliminate unwanted charge flow.

If excess charge appears on the positively charged insulated electrodes, (after the elimination of the known 3D sources) then the conclusion is straightforward. While the method is relatively inexpensive, one has to wait for a stormy period, and the evaluation of the results requires a large number of measurements in order to eliminate system errors. Nevertheless, at this stage of the developement this test method is the most feasible.

2) Artifical formation of B.L.
If a B.L. is to be formed artifically, there are two basic methods, similar to those of the above discussed ones.

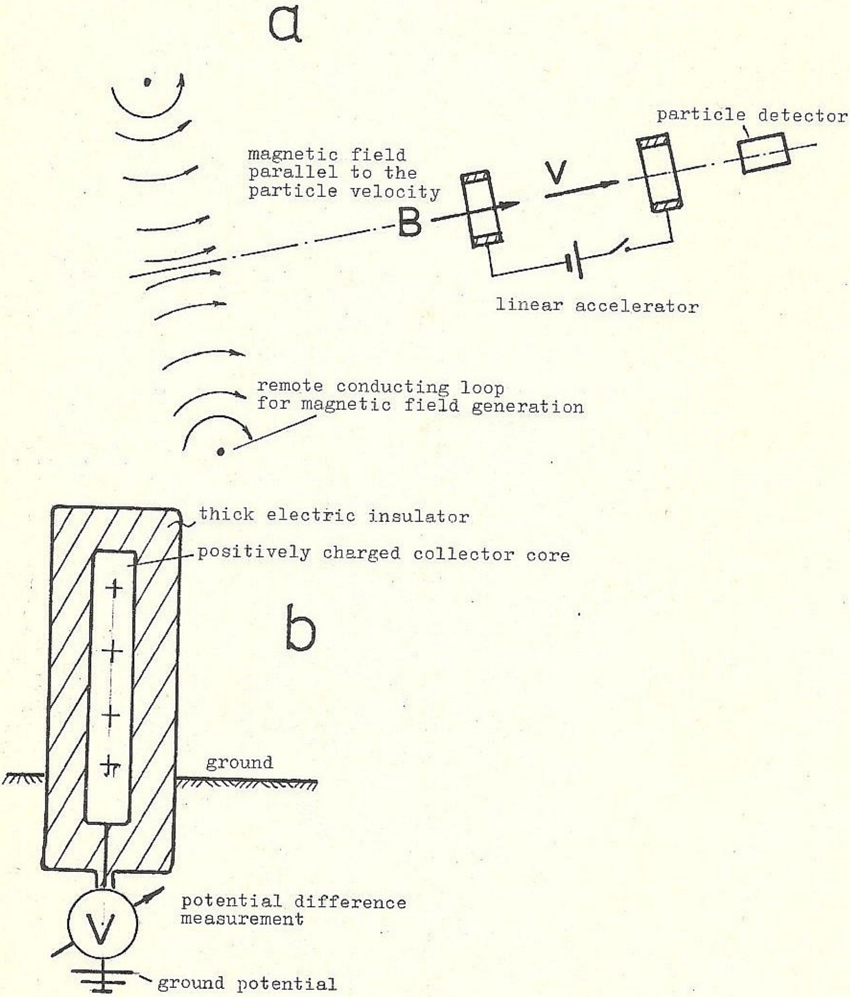
a) Inasmuch the linear accelerator is replaced by an extremely large Marx generator, in principle, a 3D REB is formed, which is turned into a 4D beam (using proper target material) with the help of the remote magnetic field. At the present state of development the cost of energy storage in the Marx generator (capacitor bank) is about 10 $/Joule. As there are losses at the generation site, and the loop of remote magnetic field is to be supplied with a separate but similarly huge capacitor bank as well, the costs are simply prohibilive. Needless to say, there are a number of unsolved theoretical and technological problems as well, so the artifical B.L. formation can not be realised in the near future.

b) The easiest way again is to help the creation of B.L. in lightnings. A similar device can be used, like the one described above but not entirely the same. The outer shell should be a material of high tensile strength in order to avoid blowup during electron implantation, charge buildup on the target. The electrical conductance of the cover should be about that of the ivet soil. Inside the shell, a conductive, but non grounded small metal core should be placed. It will attract lightning, and it will keep the B.L. in the nearby.

The B.L. monitoring could be done automatically, as it emits X-rays, and this can be detected by scintillation tubes. Each unit should have at least three X-ray detectors, and if at least two of them signal for larger than about 0.5 sec, other test equipment can be switched on.

Several phenomena can occur around B.L. and these can be experimentally investigated; anomalous electric conductance, and magnetic effects, a small, electrically charged object accelerated to a certain speed could leave a closed box - just to name some strange and unusual consequences of the multidimensional model.

Obviously this method of B.L. creation relies heavily on weather conditions, and luck in general, because strong enough lightnings are rare. Nevertheless at present this seems to be the only way to study B.L. and associated phenomena.



Appendix C Figure 1. Schematic layout of the test equipment for checking the structure of space-time

a/ linear accelerator and remote magnetic field
If the space is more than 3 dimensional, the detector does not detect electrons when the magnetic field is generated by the loop.

b/ After a streak lightning discharge some of the electrons are lifted to the additional space dimension. Usually they cannot form a B.L. These electrons could be collected by the positive core. Only 4D electrons may reach the core, thus the potential difference is less during electric storms.

Appendix D

Ostensible dimensionality effects in solid state physics

The dimensionality of an object in solid state physics is of practical importance, although this fact became well known only in the last decade.

For obvious reasons (apart from the usual 3D systems) only 2D systems can be manufactured with our present technology, and even this is technically cumbersome, because sometimes a monoatomic layer is to be produced. Then electrons move parallel to a plane only, therefore new effect spring up, which are not present in a 3D system.

Such a new effect is for example the quantum Hall effect. In this case the electron moves in a one dimensional potential well, and this results the rise of discrete energy levels - energy subbands. These effects may appear at room temperature as well.

In the 2D electron gas new quantum transport phenomena appear like the above-mentioned quantum Hall effect, thermomagnetic effects, etc.

In a 4D system the basic difference is the appearance of temperal instability the system will collapse back to the original 3D state. There are immense theoretical and technological problems in the study of 4D (more than 3 space dimensional) system
If the production of artificial B.L. could be realised, than a brand new class of phenomena could be studied in solid state physics as well. There are indirect indications that these phenomena are non-linear, that is, a certain threshold value of the external 4D magnetic field is to be exceeded in order to initiate these phenomena. The most important new phenomena are likely to be a sort of conduction and magnetic phenomena; electrically insulating 3D matter may be conductive, non ferromagnetic 3D matter may show new magnetic properties. All these phenomena are the result of a new, but unstable structure of matter.

The reorganisation, recrystallization of matter could result in the change of the shape of the originally 3D material. While these statements seem to be strange, far-fetced and qualitative, it has to be noted that there are indications that such phenomena may take place in biology

In the case of B.L., this new type of conductivity would result the temporary breakdown of electronic equipment - that is, not a permanent damage caused by a beam - during and after the existence of the 4D beam for a while. It must be noted that after the beam collapse other, stronger effects take place as well, so electronic malfunctions during the lifetime of the B.L. are the best indications for these effects. At the end of the qualitative case studies some of these observations are analysed.

Appendix E

Four dimensional beam interaction with different target materials

The trace of a B.L. impact upon solids is usually circular, and the molten part is flat, parallel with the surface, like the impact trace of a 3D electron beam. On the other hand, it is known that B.L. is usually spherical when it is in the air, so in principle its impact trace should be spherical as well. This seemingly contradictory behaviour can be understood, if the four-dimensional beam impact is analised in details. In order to accomplish this, the geometrical nature of the interaction must be cleared.

When a 4D beam penetrates through a 3D space, each point of the beam appears only once in their common segment. (That is, a beam electron appears and disappears in the 3D space). Nevertheless, as the electrons interact through their fields, and not as geometrical points, their effect will be definitely detectable, and the ionisation mechanism will be the same as in the usual case. Only the efficiency of energy transfer will be worse, as a given electron will spend a very short time in the 3D space. Most of the effect will come from those incident electrons, which will be scattered to the 3D space from the beam.

There are two cases to be distinguished:

a) When the penetration length is longer than the longest axis of the impact ellipsoid, there will be interaction in the whole volume - this is the most frequent case, air-beam interaction. This can be approximated as if the electrons appeared at the upper part of the impact ellipsoid, and moved continuously to the lower half, and there they disappear, that is, the 4D beam is approximated by a 3D beam within the impact ellipsoid, or sphere.

b) The situation is different if the penetration length is shorter than the longest axis of the impact ellipsoid. In principle the situation should be like in the previous case, but the impact mechanism will be altered as a consequence of Coulomb-force. The non-uniformly scattered electrons will repel the beam and distort its shape, so the full beam impact volume will not interact with the material, only a part of it. (See Fig 1). If the solid object is a thin plate, the case will be like interaction with air, with some repulsive force. In semiinfinite solids the impact diameter could be slightly larger than the beam diameter (due to scattering) and the depth of the impact trace will not exceed the penetration length, simply because the beam is repelled before it could penetrate into the material. Therefore the depth of the impact trace is proportional to the energy of the beam electrons for a given material, but the full amount of energy is never dissipated in such interactions, therefore all energy estimations are just coarse lower limit approximations.

Obviously, two basic ionisation mechanism prevail for B.L. interactions:

a) primary beam impact, when the concept of penetration length and stopping power can not be used in the usual sense,

b) impact of the 3D scattered beam electrons, which is a routine calculation.

For air-beam interactions case a) is the more important, and for solid target - 4D beam the case b) seems to be the more important, due to enhanced scattering.

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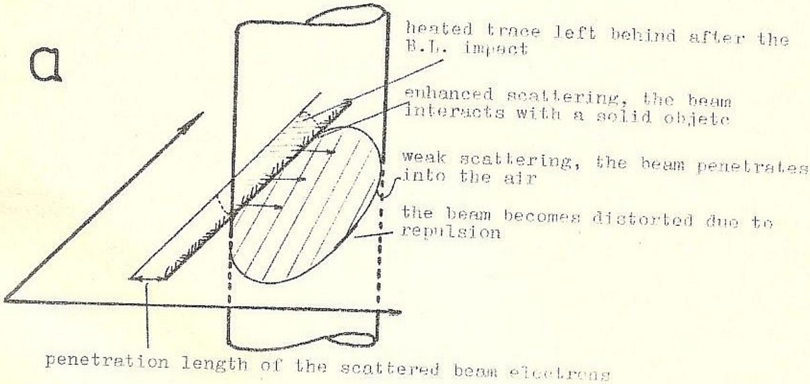

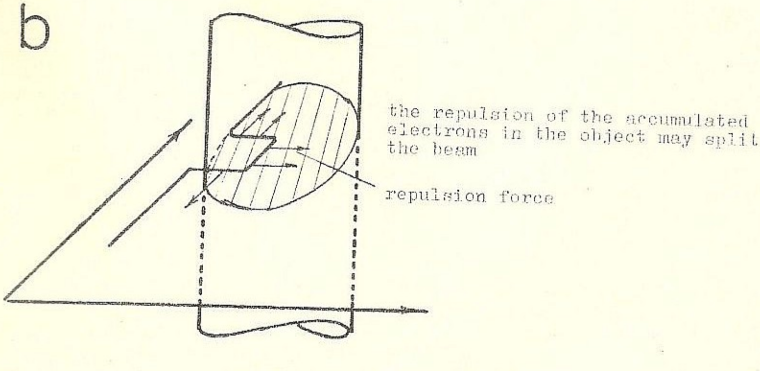

Appendix E Figure 1. 2D analogy of beam interaction with solid objects

a/ The electron scattering is uneven and this distorts and repels the beam. The beam cannot penetrate deeply into the object due to this repulsion.

b/ If the beam is colliding with an oblong object, protruding deeply into the object, it is heated in its total volume, and part of the scattered electrons accumulates inside it.

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