NASA TECHNICAL NOTE **NASA TN D-3188**

NASA TN D-3188

N66-15316 (ACCESSION NUMBER) | (THRU)

40 (PAGES) | 1 (CODE)

(NASA CR OR TMX OR AD NUMBER) | 25 (CATEGORY)

FACILITY FORM 602

GPO PRICE $ ______

CFSTI PRICE(S) $ 2.00

Hard copy (HC) ______

Microfiche (MF) .50

ff 653 July 65

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1966

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SUMMARY

Surveys of NASA Lewis Research Center personnel were conducted to obtain information about ball lightning occurrences. A comparison of the frequency of observation of ball lightning with that of ordinary lightning impact points reveals that ball lightning is not a particularly rare phenomenon. Contrary to widely accepted ideas, the occurrence of ball lightning may be nearly as frequent as that of ordinary cloud-to-ground strokes.

Detailed descriptions of 112 ball lightning events were obtained. Correlation techniques applied to the set of descriptions failed to pick out any strong connection between factors such as brightness, size, duration, or color. This result, along with the reported constancy of appearance of the balls, makes it appear unlikely that they represent the slow dissipation of stored energy.

Ball lightning diameter estimates follow a log normal distribution. Such a distribution also represents the quantity of charge in lightning strokes and has been associated with the field intensities in sferics (electromagnetic disturbances) from thunderstorms. The similarity of these distributions, while certainly not conclusive, suggests that such quantities may be related.

Two different categories of events are tentatively identified among those reported. In one the ball appears after a lightning stroke to ground and remains and ends near the ground. In the other the ball is first seen in midair and remains aloft, vanishing without noticeable disturbance.

INTRODUCTION

Reports and observations concerning the phenomena labeled "ball lightning" have appeared for centuries. The subject has become enmeshed in folklore, with stories concerning the behavior of ball lightning that are indeed marvelous and strange. Intermittent scientific interest in this subject has intensified within the past decade. The possible connection of ball lightning with plasma physics is partly responsible for such renewed attention.

Various summaries of reports on this phenomenon have been published. Recent surveys by McNally (ref. 1) and Dewan (ref. 2) and two bibliographies (refs. 3 and 4) are particularly useful. In one case, a circuit breaker aboard a submarine was reported to emit a luminous sphere which may be of similar character (ref. 5). Descriptions of ball lightning observations such as those quoted by Stekol'nikov (ref. 6) include a great variety of appearances and behaviors. Numerous physical models have been proposed to account for the formation and continuing existence of a lightning ball. These include models based on the assumed plasma character of the sphere (refs. 1, 2, 4, 5, 7 to 12) as well as one based on inhomogeneous space charges (ref. 13) and another using chemical processes (refs. 14 and 15). One of the barriers to a satisfactory model has been the assumption that the mechanism must account for stored energies on the order of 10^6 joules. These energies are deduced from reports of one or two instances.

One difficulty in dealing with this subject is the lack of agreement as to a definition of ball lightning. The term has been applied to almost any type of aerial luminosity. Some of the occurrences can undoubtedly be explained in terms of corona discharges or Saint Elmo's fire. Others might be incandescent or burning material thrown from the point of impact of a lightning bolt. A wide variety of less probable mechanisms can be invoked to account for isolated observations. Finally there is always the possibility that any particular report may be inaccurate. Some investigators, using the etymological approach, apparently feel that the ball lightning label should be restricted to phenomena that are literally lightning in the shape of a ball. Such an approach may be the source of occasional disputes as to whether ball lightning exists.

To avoid such difficulties, this report will adopt the lexicographical approach and accept as ball lightning any phenomenon that an observer has so labeled. As a consequence, fundamentally different phenomena may be included.

Although not in complete agreement, the summaries of ball lightning reports generally indicate that very wide ranges of size, duration, color, brightness, and motion have been attributed to ball lightning. Sizes range from a few centimeters up to many meters; durations from a fractional second up to tens of minutes. Nearly all colors have been cited, and motions have been reported in diverse directions and velocities. The very range of characteristics seems immediately to imply either observational inaccuracies of great extent or a diversity in the types of phenomena included.

Certain accounts imply that ball lightning may involve substantial amounts of energy (on the order of 10^6 J). Any process capable of storing such energy or of confining an energetic plasma for appreciable periods is of obvious interest. Nevertheless it must be stressed that the occurrences from which such energy estimates can be made are but a tiny fraction of the total reported, actually only a few total instances. On the other hand, many reports are available implying negligible energy, glowing spheres that disappear quietly.

Theoretical models that have been proposed have often been criticized for their inability to account for the extreme, high-energy manifestations of ball lightning. It has been repeatedly pointed out, for example, that the 10^6 joules sometimes associated with a lightning ball exceeds the energy involved in the ionization of an equivalent volume of air. Furthermore, the recombination of such a volume of ionized gas would take place with great speed. Such considerations led Kapitza (ref. 4) to propose a mechanism that depends on the postulated existence of an intense electromagnetic radiation to supply a continuous energy input. A plasma spheroid so sustained would exhibit a characteristic dimension related to the radiation wavelength; it would also tend to move in a manner unrelated to air movement.

Such a process would explain some of the reported ball lightning features: constancy of size, erratic motion, even a possible small bang as the sphere collapses. Unfortunately there appears to be no other evidence for the existence of such intense and prolonged naturally occurring radiation. It might well be possible to use such a system to produce a spherical plasma in atmosphere, but this would not prove that any of the ball lightning phenomena arise in like manner.

The ball lightning phenomena are not easily studied. The occurrences are unpredictable and sufficiently infrequent to minimize the chances of bringing analytical instruments to bear. Consequently it is advisable to attempt to extract the maximum amount of information from those occurrences that have been observed even though the circumstances of the observations may preclude a high degree of accuracy. In principle, given a large body of observations of these phenomena it should be possible to use correlation techniques to extract significant relations among the characteristics and circumstances of the observations. One might say that the signal-to-noise ratio in the raw data is low, but that the signal can still be extracted by the processing of a sufficient quantity of data.

This report describes a pair of surveys conducted among the employees at NASA Lewis Research Center. The first questionnaire located persons who had observed ball lightning; the second obtained detailed descriptions of such observations. In evaluating the results of the questionnaires, a simple correlation technique was employed to determine whether factors of occurrence, behavior, and characteristics were connected in a manner implying functional relations. The descriptions were also examined and compared in an attempt to identify fundamentally different types of ball lightning events.

A study of this type depends for its success on the cooperation of a large number of people. The interest and enthusiasm of those responding to the surveys is deeply appreciated. Thanks are due to Dr. G. Rand McNally, Jr., of Oak Ridge National Laboratory both for permission to cite his unpublished results and also for his helpful comments on the preliminary draft of this report.

FIRST SURVEY

A questionnaire, shown in appendix A, was distributed to approximately 4400 employees in April 1963. It sought information concerning the frequency of observation of ball, bead, and ordinary lightning as well as information concerning the frequency of exposure to thunderstorms. An added question asked whether the observer would be more inclined to watch or not to watch given the opportunity. The responses of 1764 observers are tabulated in table I.

The question concerning attitude revealed that 930 preferred to watch

TABLE I. - RESPONSES TO PRELIMINARY QUESTIONNAIRE

Lightning	Times seen						Total number observing
	No answer or 0	1	2	3	4 to 8	>8	
Ordinary (impact)	1355	179	179		34	17	409
Ball	1584	111	34	6	29		180
Bead	1652	39	30	10	33		112

Observer location	Thunderstorm exposures per year				
	No answer	0 to 1	2 to 3	4 to 6	>6
Outdoors	22	746	716	185	101
Automobile	30	300	[illegible]	380	165

lightning displays, 105 preferred not to watch them, and 718 had no preference. The question was not answered by 11.

The first survey was intended primarily to locate observers of ball and bead lightning from whom more detailed information would be requested. The additional questions concerning exposure frequency and attitude, as well as the query on ordinary lightning impact observations, served to encourage responses from people who had witnessed neither ball nor bead lightning. In addition, the ordinary lightning observations could be used to provide a rough comparison of the frequency of occurrence of the various forms.

The results reveal immediately that ball lightning as defined herein is not particularly rare. The number of persons reporting ball lightning observations is 44 percent of the number reporting observation of ordinary lightning impact points. The bead lightning observers were fewer, about 27 percent as numerous as the ordinary lightning impact observers. The total number of observations of each type, accounting for multiple observations, can be used to provide similar ratios. The ratio of ball lightning to ordinary lightning observations reported is about 0.37; the ratio of bead lightning to ordinary lightning observations is about 0.33.

The above figures represent the relative frequency of observation. The much more significant frequencies of occurrence can be deduced by taking into account the relative observability of each type. The definition of the ordinary lightning impact point used in the questionnaire was intended to provide phenomena with an observability nearly the same as that for ball lightning. The observability of a beaded lightning stroke should be substantially greater than that of the other types. From the numbers obtained, the frequency of occurrence of ball lightning phenomena may be estimated as 0.1 to 1.0 times the frequency of ordinary lightning strokes to ground. Beaded lightning might similarly be estimated to occur with a frequency less than 0.003 times that of ordinary ground strokes. This assumes that beaded strokes are observable more than 10 times as far away as the ground impact points.

The frequency of occurrence of ball lightning deduced herein is at variance with that assumed by most writers on the subject. The literature is liberally sprinkled with such terms as "rare form of lightning," "unusual luminous forms," "relatively rare phenomenon," and "rare events." It is true that an individual will rarely observe ball lightning. From the results herein, only about ten percent of the people responding to the first questionnaire had observed it. But by the same criterion, one should also call ordinary lightning strokes to ground "rare events" in that only about 23 percent had seen such strokes at close range; however, most people do not consider ordinary lightning as "rare." Therefore, such terminology applied to ball lightning gives the impression that it is much less frequent than ordinary lightning, which according to this survey is incorrect.

The frequent occurrence of ball lightning events has interesting consequences. Principally, it demands that any explanation put forth to account for a significant fraction of such events not depend on extremely unlikely circumstances. For example, it would appear unprofitable to search for mechanisms based on extremely large stroke currents (say over 100 000 A). As another example, one source (ref. 12) suggests that an ordinary bolt striking very near a surface with an aperture might produce a plasmoid in a manner similar to the generation of a smoke ring. Obviously the fraction of events attributable to such a process is completely negligible.

The frequencies found would not be incompatible with the possibility that many or even most lightning strokes to ground generate ball lightning; however, it would be rash indeed to leap to such a conclusion.

SECOND SURVEY

Followup questionnaires of the form shown in appendix B were distributed to those responding affirmatively in the first survey. Returns were received describing 112 ball lightning events. This questionnaire was designed to provide a large amount of information concerning the circumstances in which the event was observed, the behavior and characteristics of the phenomenon, and also the extent to which after effects were noted. The form of the questionnaire, forcing responses to be placed in preselected categories, facilitated subsequent statistical treatment. In addition, for each of the 56 specific questions a space was provided to permit an indication of the degree of certainty. This was intended to encourage people to answer according to their best recollection, even though they were unsure of its accuracy. The certainty factor could then be used in processing the results if needed.

On the questionnaire reproduced in appendix B, the numbers in the blanks represent the total responses. The certainty column responses are not indicated, because they act only to modify the significance of the primary answers. The distribution of certainty responses is shown at the end of the questionnaire. Appendix B includes the coding used to convert the descriptions to a form amenable to machine processing. The coded form of the complete set of 112 event descriptions is given in appendix C.

PROCESSING OF RESULTS

The distribution of responses to many of the questions is in itself of considerable interest, indicating the range of characteristics that may be associated with ball lightning. This is the sort of information that has previously been collected, although the present study covers more factors than did most previous ones. The original objective of this study was to determine whether significant correlations could be traced between descriptive parameters. To do this it was convenient to divide the responses to each of 46 questions into two categories, striving to maintain an appreciable fraction in each. This binary arrangement of responses is indicated in appendix B by the asterisks following the code numbers. For a given question, the asterisked responses are combined to give the class a response; the double asterisk similarly indicates class b response. Various exceptions and special cases are indicated by footnotes.

The χ^2 test was applied to the data in the binary (grouped) form to determine whether significant relations existed among the 46 parameters. This test is commonly used to determine whether two quantities may be related (or more precisely, to test the hypothesis that they are unrelated). A detailed treatment may be found in any standard text on statistics (e.g., see p. 252 of ref. 16).

The calculations of χ^2 can best be shown with an example. Take the reported brightnesses and durations of the ball lightning events (columns 29 and 42). The two brightness classes are (a) those described as either "as bright as an ordinary lightning stroke" or "bright enough to illuminate nearby objects" and (b) those described as either "bright enough to be clearly visible in daylight" or "bright enough to be barely visible in daylight." The two duration classes are (a) those described as lasting 6 seconds or less and (b) those lasting more than 6 seconds. All the events for which estimates of these two parameters were made can be listed in a two-way table, as shown in table II. The number in each of the four blocks is the number of events reported to have the indicated combination of characteristics.

For the general case of a table with r rows and c columns, the equation for χ^2 can be written

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(N_{i,j} - N'_{i,j})^2}{N'_{i,j}}$$

where $N'_{i,j}$ is the expected value for $N_{i,j}$ obtained from the relation

$$N'_{i,j} = \frac{R_i C_j}{N}$$

In the case of the two-way table, the

TABLE II. - BRIGHTNESS AND DURATION DESCRIPTIONS OF BALL LIGHTNING

Brightness	Duration		Totals
	Class a (short)	Class b (long)	
Class a (more bright)	$N_{a,a} = 13$	$N_{a,b} = 19$	$R_a = 32$
Class b (less bright)	$N_{b,a} = 33$	$N_{b,b} = 29$	$R_b = 62$
Totals	$C_a = 46$	$C_b = 48$	$N = 94$

above equation for X^2 can be simplified to

$$X^2 = N \frac{(N_{a,a}N_{b,b} - N_{a,b}N_{b,a})^2}{R_aR_bC_aC_b}$$

which, when the numerical values are inserted, gives $X^2 = 1.34$. The significance of a given value of X^2 depends on the degrees of freedom, which for an r-row, c-column table is the product (r - 1)(c - 1). For this example, with one degree of freedom, there is a probability of about 0.25 that values of X^2 exceeding 1.34 will arise through chance alone (ref. 16, p. 401). The result is compatible with the hypothesis that the parameters are unrelated. Consequently, no conclusion can be drawn concerning a possible relation between ball lightning brightness and duration.

Significant information may have been lost when the answers to each question were collected into only two groups. The original coding of the questionnaire responses provided four brightness descriptions and eight duration descriptions. Ideally, a four-by-eight table should have been used to calculate X^2; however, the number of descriptions is too limited to make such a calculation meaningful. When the expected number for any block in table II falls below four or five, the tabulated probabilities associated with values of X^2 become very approximate.

A digital computer was used to compute values of X^2 for all the 1035 relations among the 46 parameters. From such a large number, some apparently significant correlations can be expected to appear purely by chance. The intent of the study was not to establish or prove rigorously the existence of significant correlations, but merely to locate correlations of possible significance that might provide some insight into the ball lightning processes.

Significance of Correlations

If various fundamentally different phenomena are included in the reported observations, the correlation technique used can be expected to give relatively weak correlations. Suppose that the set of observations includes phenomena of types A, B, C, etc. If two characteristics such as diameter and duration are strongly related in type B but unrelated for the others, the maximum value which may be anticipated for X^2 becomes

$$X^2_{max} \approx \frac{N_B^2}{N}$$

where N_B is the number of events in category B. This is in contrast to the maximum value for completely correlated characteristics of

$$X^2_{max} \approx N$$

when the relation exists throughout the entire set.

For a set of 100 reports, such as that being discussed herein, a subset of 20 might give an overall correlation of the order $\chi^2 \approx 4$. When the effects of random variation in report accuracy are included, it appears evident that subsets this small would not give strong evidence of their presence.

Identification of Types of Ball Lightning

Another technique was used in the attempt to identify categories or types of phenomena reported as ball lightning. Thirty of the 46 parameters were selected as being most apt to distinguish between such types. Each reported observation was thus characterized by a set of 30 indexes. The binary (grouped) form of the descriptions was used. Class a responses were assigned the numerical value -1, class b responses the value 1, and no response the value 0. Each of the 112 ball lightning descriptions was thus transformed into a set of 30 numbers. In this form it could be considered to correspond to a point in 30-dimensional space with its location along any dimension given by one of the values -1, 0, or 1. A measure of the dissimilarity of two descriptions is the distance separating their corresponding points. The distance between the k^{th} and r^{th} points $S_{k,r}$ is given by

$$S_{k,r}^2 = \sum_{i=1}^{30} \left(x_k^i - x_r^i\right)^2$$

where x_k^i is the location of the k^{th} point along the i^{th} dimension.

A computer program was set up to arrange the 112 event descriptions in an order such that the sum of the S^2 between each point and the two preceding points

$$S_{n,n-1}^2 + S_{n,n-2}^2$$

was minimized. The starting point was taken to be the origin $x^i = 0$. In the event of ties, the distance to the third preceding point was used to control the selection. This procedure yielded an ordered list of the 112 descriptions, with an indication for each of its distance from the preceding two points. If a number of descriptions were basically similar, they should appear as a group in the sequence with relatively small interevent distances.

DISTRIBUTION OF RESPONSES

Some tentative conclusions can be drawn from the distribution of responses to the questions. Such data must be interpreted cautiously, since they represent the combination of three factors: the actual frequency of occurrence, the observability, and the observer error. What is desired is, of course, the actual frequency of occurrence. This may differ considerably from the reported frequency.

If for a given parameter p the reported frequency distribution is $f_r(p)$,

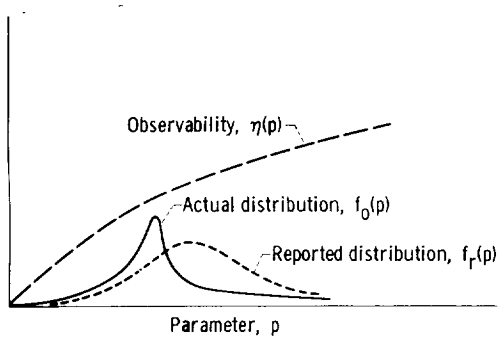

Figure 1. - Possible relation between actual and reported frequency distributions, reflecting both observability and observer error factors.

it is related to the actual frequency of occurrence $f_o(p)$ by

$$f_r(p) = \int_0^{\infty} \eta(p^*) f_o(p^*) G(p,p^*) dp^*$$

where $\eta(p)$ symbolizes a relative observability coefficient and $G(p,p^*)$ represents the probability that an occurrence at p^* will be reported at p.

Such an equation is of little practical use, because of the difficulty in assigning functional form to either the error or the observability parameters. The relation does point out the obvious extremes; that a reported distribution could be the actually occurring one with uniform observability and no error or that it could be only the observer error applied to a single-valued phenomenon. It also appears obvious that unless the error and observability parameters are very peculiar in their form, their effect should be to broaden and possibly displace any peak that exists in the real distribution. This effect is demonstrated by the curves sketched in figure 1. The error parameter $G(p,p^*)$ is not shown but may be considered Gaussian in character. This figure serves to indicate that the reported distributions should be taken only as possible representations of the real events. It is conceivable that peaks apparent in the reported distributions might result only from the observability factor; however, any statistically significant peaks in the reported frequencies should generally correspond to sharper peaks in the actual frequencies.

Ball Lightning Duration

The distribution of duration estimates obtained in the present survey is compared with that obtained by McNally (ref. 1) in figure 2. The two distributions are not identical but follow very closely the same form. In both surveys the observer was free to indicate any duration, by filling in a blank (McNally's survey) or by checking a location on a continuous scale. The present survey obtained such estimates from only 95 observers, as compared to the 447 obtained by McNally.

For both surveys, the frequency with which a given duration is observed (corresponding to the slope of the plotted curves) is greatest for durations less than 5 or 6 seconds. These short-duration estimates are fairly uniformly distributed; the present study provides some indication of a most probable duration in the 4 to 5 second region. Both studies agree that a substantial fraction, 8 to 12 percent, are described as lasting for over 30 seconds. The median duration for the present data is about 6 seconds; for the McNally curve the median is less than 4 seconds. The difference between the two distributions could be the result of the differing populations and geographical locations from which the data were drawn. They could also be attributed to the small size of the present sample.

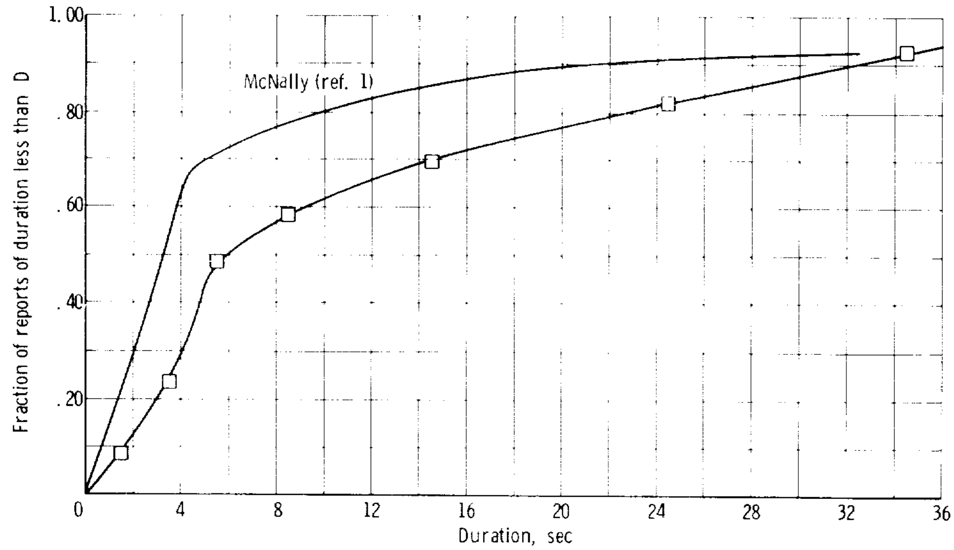

Figure 2. - Distribution of reported ball lightning durations; present survey data shown with that of McNally (ref. 1).

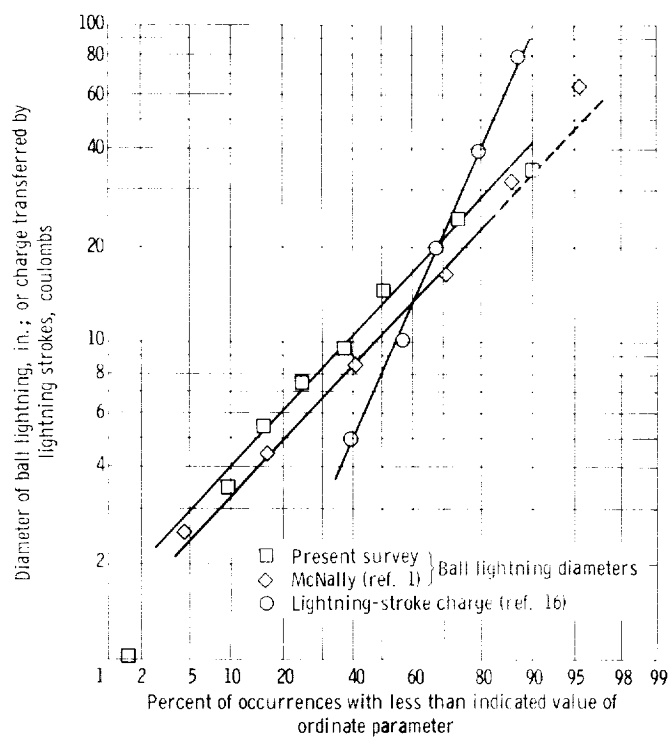

Figure 3. - Log normal distributions of ball lightning diameter estimates with similar distribution for charge transferred by lightning strokes.

In attempting to connect the observed duration distribution with a ball lightning mechanism, it must be borne in mind that the durations estimated are not the durations of the ball lightning phenomena but rather the durations of the observations. In the present study, 56 percent of the observers reported that the ball was not seen to originate; 30 percent reported that it was not seen to end. Such fractional observations will tend to increase the frequency of the short-duration observations in comparison to the frequency of the actual occurrence durations. On the other hand, the probability that an event will be observed undoubtedly increases with its duration. In addition, systematic observer error must be considered. A brief, highly stimulating event is apt to have its duration overestimated. These effects should be partially compensating. Nevertheless, the reported distribution of ball lightning observation durations should be expected to differ somewhat from the actual distribution of ball lightning durations.

Ball Lightning Diameters

Various characteristic diameters for ball lightning have been given by different authors. The distribution of diameter estimates obtained in the present survey is plotted in cumulative or integrated form in figure 3. If a probability scale is used on the abscissa and a logarithmic scale on the ordinate, a fairly good straight-line relation is obtained both for the present data and for that of McNally (ref. 1). The median of the distribution appears at about 14 inches for the present survey and at about 10 inches for McNally's data. The slope of the two faired curves is about the same.

The straight-line relation in figure 3 demonstrates that the ball lightning diameter estimates follow a log normal distribution. The standard deviation is approximately log (2.5); that is, about 84 percent of the estimates fall below a diameter 2.5 times the median.

Also plotted on figure 3 is the distribution of charges in lightning strokes, as given on page 338 of reference 17. This log normal relation shows a standard deviation of log (7.0), or about twice that for the ball lightning diameter curves. The square of the ball lightning diameters would thus follow a log normal distribution with a standard deviation nearly the same as that for the lightning stroke charge. Such a correspondence suggests that the two quantities may in some manner be related.

The possibility that the reported diameter distribution might reflect merely observer error cannot be ignored. A logarithmic error might be expected; that is, the observer might say the diameter was 10 inches, give or take a factor of two. In addition, the varying observability of different size lightning balls should produce a reported distribution different from that actually occurring.

Other thunderstorm phenomena have been described as following the log normal type of distribution. The intensity of the electric field associated with thunderstorm sferics (electromagnetic disturbances), as well as the current and current rise rate in lightning strokes, has been so characterized (ref. 18). Connections among these phenomena are not difficult to imagine. The connection between any of these and the diameter of a lightning ball is less obvious. Nevertheless, the similarity of the distributions suggests that possible relations should be explored.

Distribution of Distances

Two questions pertaining to the distance between observer and lightning ball provided interesting information as to relative frequency of observation. One asked the distance at which the ball was first seen, the other the closest approach to the observer. Obviously, such distance estimates can be expected to have a very low precision.

The distribution of reported distances may be thought of as representing the interplay of three factors. First, of course, is the frequency of occurrence, which might be expected to increase with distance squared or cubed. (Distance squared implies a uniform random occurrence over the earth's surface; the cube implies uniform random occurrence throughout a volume of atmosphere.) The second factor is the visibility of the phenomenon. An average vista would possess sufficient nearby obstructions to reduce the visibility of distant objects. Falling rain would in many instances greatly reduce visibility; visibility would decline as distance squared even under ideal conditions for a weakly luminous object. The third factor can be called noticeability. It is highly likely that many ball lightning events are seen but not recognized as such.

The observation frequency with distance could be considered the product of these factors. Unfortunately, it appears impossible to prescribe the visibility and noticeability relations accurately enough to decide which relation the occurrence follows.

The distance at which the ball was first seen is estimated to have been under 50 feet for half the cases. If we exclude those reports that locate the occurrence in a building-covered area the fraction under 50 feet is 0.32. The minimum distance from the observer is given as less than 10 feet in 32 percent of the reports and as under 100 feet for 66 percent. Separating the data according to the location of the observer shows that over half had a minimum distance under 10 feet when the observer was located within a building. For observers in vehicles or outdoors, exactly half are estimated to have come within 100 feet.

Such figures imply a drastic reduction in either visibility or noticeability at distances beyond about 100 feet. Other things being equal, the probability of ball lightning being observed should be proportional to either the ground surface area or to the atmospheric volume within the observer's field of view. The number reported at distances less than L should therefore increase either as L^2 or as L^3 up to some distance at which observability diminishes. Figure 4 shows these two hypothetical distribution curves adjusted so that half the observations are within 100 feet. All the observations should be within 127 or 141 feet if the L^3 or L^2 relation continued up to some observability cutoff.

On this basis it is possible to make some rough estimates of the potential

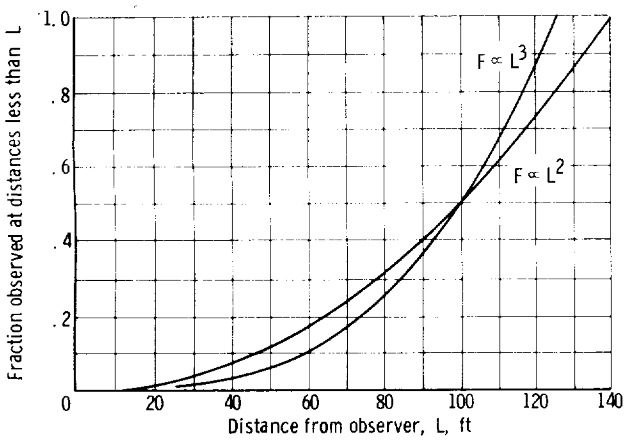

Figure 4. - Idealized distribution of ball lightning occurrences, assuming the frequency to depend either on L^2 or L^3 and assigning distance cutoff such that half occur within 100 feet of observer.

observability of ball lightning. The original survey revealed that about 10 percent of the persons questioned had seen ball lightning. If it is assumed that the mean observation span was about 25 years, the probability of a given person seeing ball lightning in a given year is about 1/250: In view of the short range of the average observation it appears likely that as many as 100 or 1000 times the observed number actually occur within 500 feet of an observer. This fact suggests that an observer with a good vantage point watching carefully for ball lightning during appropriate weather should have a fair chance of seeing one during a given year.

Ball Lightning Motion

Questions that might pertain to the motion of the ball included queries as to the wind velocity, the maximum and minimum velocity of the ball, and any apparent guidance to its motion. Although only about half the observers were willing to venture a guess as to wind velocity, their estimates were nearly uniformly distributed over velocities up to 40 miles per hour with a declining number at higher values. Estimates of the maximum velocity of the ball were grouped below 20 miles per hour (70 percent) with a small group being given speeds above 60 miles per hour (17 percent). Minimum velocities were similarly grouped with 54 percent estimated to be below 5 miles per hour and 86 percent below 15 miles per hour. The most popular category in response to the guidance question was "no guide" (39 percent). Relatively few were thought to follow either the ground surface (18 percent) or power and telephone wires (14 percent).

The question as to the manner of motion of the ball revealed a marked preference for mostly horizontal motion (54 percent) rather than mostly vertical (19 percent). The motion of the ball can then be said to be apparently slower than the wind velocity, with little obvious guidance, and to be more horizontal than vertical. If in fact the ball moves contrary to the wind, as was implied in a case involving a Soviet aircraft (ref. 19), some substantial energy must be acting to control its position or movement. The Kapitza model locates the ball according to the pattern of reflected radio-frequency waves, thus making its motion independent of the local air velocity. However, if air is to flow through the ball and be ionized in transit, the energy required to maintain the ball should increase with flow rate.

Miscellaneous Characteristics of Ball Lightning

Brightness. - The most favored of the four categories was "bright enough to be clearly visible in daylight" with 60 percent of the responses. Very few were described as "barely visible in daylight" (8 percent), and those called "bright as an ordinary lightning stroke" were likewise rare (11 percent).

Shape or appearance. - Most reports described the ball as round (87 percent) and uniformly bright (76 percent). The favored colors were orange and yellow, often in combination with others. In McNally's survey red was more frequently mentioned. In both, a substantial number were described as blue, blue-white, or white. Rather surprisingly, 36 percent reported an impression of spin or rotation of the ball. Although McNally did not include a specific question on this point, his reports included about 9 percent that volunteered such a description.

Continuity. - A substantial majority of the reports (over 85 percent in each instance) concurred that the size and brightness of the ball remained about the same during the observation and that the appearance did not change noticeably even immediately prior to its disappearance. Such reports are hard to reconcile with any proposed mechanism wherein stored energy is being dissipated. They would possibly fit the Kapitza mechanism of resonant absorption of radio-frequency energy but even then would place constraints on the nature of the radio-frequency source.

CORRELATIONS

Possibly significant correlations among the parameters are listed in appendix D. The quantity X^2 was calculated for each pair of parameters by using the data in its binary form. This was done both for the total data set and also for a selected subset comprising those answers associated with a certainty of 40 percent or greater. Thus the selected subset should be more significant because it excludes descriptions where the observer may have been guessing rather than remembering. On the other hand, this procedure may exclude some of the best reports. A careful observer may assign a low rating to his certainty just to be safe. Nevertheless, on the average the more certain answers in the selected subset should give more significant correlations.

In appendix D, all correlations are listed for which either set yielded a value of X^2 exceeding 4.0 or for which both sets gave values of X^2 exceeding 2.7. The associated probabilities for chance occurrence are 0.0455 and 0.10. Obviously among such a large number of parameters many will show such values from chance alone. The inclusion of a correlation must not be taken as proof for a connection between the parameters.

The plus or minus sign associated with X^2 indicates whether the two factors are more apt to coincide or to be mutually exclusive. In the listing, brief phrases are used to describe the factors. More exact definitions can be obtained by consulting the binary coding scheme in appendix B.

The symbols P and I stand for predictable and insufficient data, respectively. A correlation was termed predictable when the two quantities were obviously not independent, regardless of the nature of the ball lightning. An extreme example of such quantities is the combination "Events accompanied by sound" and "Ended quietly", columns 36 and 49. The very large value of 15.5 for X^2 and the negative sense merely confirm the logical consistency of the reports. The "insufficient data" symbol is applied to those cases where any one of the blocks in the two-by-two array had an occupancy less than five. Although such correlations may be significant, the computed value of X^2 can be misleading.

One goal of this study was to locate possibly significant correlations in order to be guided in constructing and evaluating models for the ball lightning phenomenon. The value of missing correlations should not be overlooked. The absence of any significant correlation between the ball diameter and its duration, for example, is somewhat surprising.

The 45 parameters studied can be separated into three broad categories:

(a) Those dealing with the behavior and characteristics of the ball itself

(b) Those dealing with the environmental circumstances under which it was observed to occur

(c) Those pertaining to the observer and his relation to the event

Of primary interest are those factors in (a) and (b) that appear to have some relation. Factors involving (c) may be expected to reflect such things as relative observability, or systematic observer error without casting much light on possible processes that could create or sustain the ball. All the cross-correlations among the 45 parameters are included, however, and those without apparent physical significance may have some psychological significance.

Detailed discussion of the probable meaning of each of the observed correlations is scarcely feasible. In the following section only those relations that seem most relevant to the ball lightning processes will be treated.

An examination of the relations involving columns 22 and 24 seems already to provide an indication that at least two different types of events are being described. In one, the ball is seen to originate following a lightning stroke to ground and is seen to end on or near ground. The occurrence is apt to be in the middle of a storm with wind velocity over 20 miles per hour. In the other, the ball is first seen in midair at some distance (over 50 ft) from the observer and is not seen to originate. Sizes, durations, and color were diverse (do not correlate). It does not approach a solid, nor does its motion seem guided. The wind velocity is usually low. It ends with a bang still in midair. For the balls originating in midair, the exclusion of the doubtful responses greatly reduced the strength of the correlations with low wind velocity, unguided motion, and unseen origin. This reduction is not primarily due to a great reduction in the number of usable descriptions. Over 60 percent of the original number were retained for each of these three combinations. In these cases it appears that the original correlation depended strongly on descriptions given by observers not too confident in their accuracy.

Ball diameter appears to correlate most strongly with the distance from the observer. Possibly this results from two effects: first, the smaller balls are only noticed when near; second, the observer who is estimating both distance and size will have similar errors for both. If the size is underestimated, so will be the distance. More surprising is the lack of significant relations with such parameters as brightness, duration, velocity of motion, or aftereffects.

The brightness of the ball had few correlations. As might be expected, those seen at night were thought to be brighter. Otherwise, the interesting association is with the impression of spin or rotation. This too could have an explanation based on the observer: unless the ball is fairly bright no impression of structure can be gained. The same observer-based explanation would, however, also predict a correlation with size or distance. Since these do not appear, it seems more likely that the correlation is a physical one. It is interesting to note that the correlation between brightness and being seen in daytime becomes insignificant when the doubtful answers are excluded. On the other hand, the connection with spin or rotation becomes stronger.

The color of the ball, arbitrarily categorized into those described as orange or yellow and those not including these two colors, seems to connect directly to the proximity of the ball to solid matter. Orange or yellow colors would be expected when the ball touched almost any object and acquired a trace of sodium or carbon particles. The correlations are not particularly strong.

The motion of the ball was chiefly horizontal for long-duration, high-velocity cases tending to occur late in a storm. The motion seemed guided for those cases where the ball did not begin and end in midair, as might be expected.

The occurrences of shorter duration (under 6 sec) correlate with few of the other factors. There is an indication that those events were more likely to end with a bang. It also appears that those few events reported to be unconnected with a storm were usually of long duration. Again we find no strong connection with any factors which might be expected to be significant, particularly brightness, size, color, and the manner of origin.

The most probable explanation for the recurrent noncorrelation among factors which should be related is that the set of reports being studied describes a number of types of phenomena. This seems more plausible than either the assumption that these factors are actually unrelated or the assumption that observer error is so extreme as to obscure a real relation.

The assumption of a number of types of events, though, is not sufficient to explain the lack of correlation. It is necessary in addition to assume that the correlations that exist within one type are obscured or counterbalanced by noncorrelation or by opposite correlation within the remainder.

The two basically different models for ball lightning can be examined with regard to the distribution of reported characteristics and the correlations. The stored-energy concept would seem to predict some variation in observable parameters over the lifetime of the ball. It should also predict some fairly

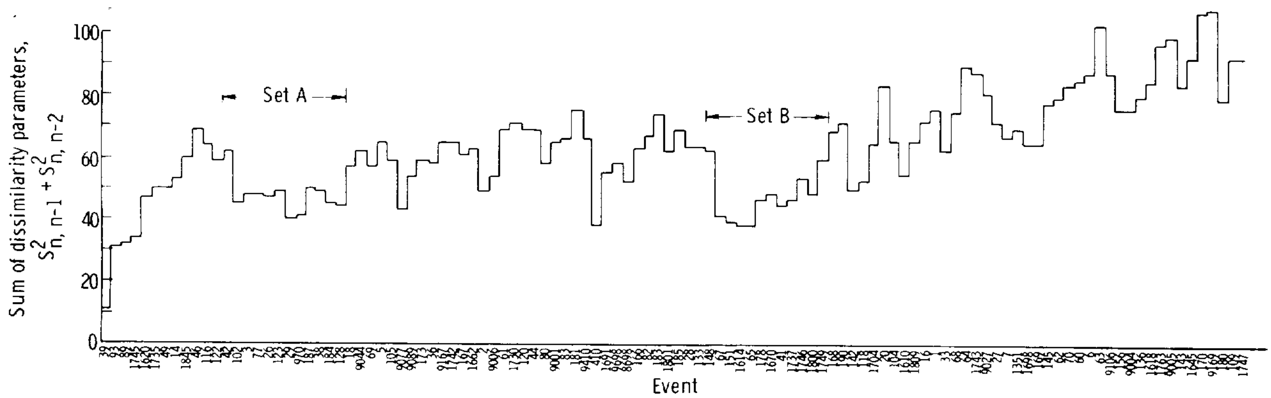

Figure 5. - Ball lightning events ordered by minimizing dissimilarity to two preceding events.

strong correlations among parameters which should be functions of the quantity of stored energy. Neither of these predictions is confirmed. The continuing input models, whether they use radio-frequency excitation, direct current through the atmosphere, or any other source, would permit the reported distribution of characteristics and also the lack of major correlations. In effect, it is possible to assume that the ball lightning is merely a side effect of some unknown primary process. All the peculiarities of ball lightning can then be conveniently relegated to this unknown primary source. Such a conclusion, however, is not logically defensible.

DIFFERENT TYPES OF BALL LIGHTNING

A search for identifiable types of phenomena among the reported events was conducted using various techniques. For example, one report seemed to be a classic description of Saint Elmo's fire. The other reports were examined (by computer) to determine the degree of similarity to this report. None were found that were close enough to justify grouping them as cases of Saint Elmo's fire. Another approach was to select the reports that seemed to indicate an above-average energy for the ball. This subset, which was then examined for correlation among the parameters, showed no significant results. The only technique which was found to provide an indication of the existence of separate types of events was that previously described: the ordering of the reports according to their location in 30-dimensional binary space.

The results of this program are shown graphically in figure 5. Starting at the origin, which would correspond to a report with no answers, the computer selected the reports so that each is the closest remaining report to the last two selected. The graph gives the progression of inter-report distances along the ordered series. Basically similar descriptions should appear as a grouping of relatively short distances.

As can be seen from figure 5, such groupings are indeed dimly indicated. Two groups of 12 reports each appear. Other smaller groups may be present, but if so they are not obvious. The identification of even the two groups with types of events should be considered highly tentative. When the reports in the two groups are examined, similarities appear which reinforce the idea that two different types of phenomena may be involved. In table III are listed parame-

TABLE III. - CHARACTERISTICS COMMON TO EVENTS WITHIN EACH OF TWO GROUPS

Column	Description	Group	
		A	B
6	Events occurring in daytime	Yes	---
21	Observer saw ball originate	---	No
22	Ball followed stroke to ground	Yes	No
24	Ball first seen in midair	---	Yes
26	First seen within 50 ft of observer	No	No
27	Diameter less than 15 in.	No	No
29	Brighter than average	No	No
14a	Occurred early in storm	No	---
36	Accompanied by sound	No	No
37	Accompanied by odor	No	No
40	Ball came within 10 ft of observer	No	No
41	Ball came within 1 ft of solid	Yes	No
43	Maximum velocity under 10 mph	---	No
44	Motion seemed guided	Yes	---
45	Ball seemed to be spinning	---	No
46	Ball passed through apertures, etc.	No	No
48	Observer saw ball end	Yes	---
49	Ball ended quietly (no bang)	Yes	Yes
51	Ball ended in midair	No	Yes
52	Ball ended within 50 ft of observer	No	No
53	Final velocity under 3 mph	---	No
71	Aftereffects were reported	---	No

ters for which a group is nearly unanimous (not more than two dissents).

The greatest difference occurs in the beginning, the end, and the location with respect to the surface of the earth. Group A reports events that follow a lightning stroke to ground, approach within 1 foot of solid (presumably near the earth surface) and are seen to end on or near the ground, quietly. Group B describe events first seen in midair, which never approach the ground, and are not connected with a lightning stroke to ground. In both groups the ball lightning was reported to be larger and less bright than the average and to remain at a considerable distance from the observer.

These two groups would seem quite similar if the differences in origin were less pronounced. A ball appearing in midair could be expected to remain in midair and not approach a solid. The same type of event originating on or near the surface could be expected to end on or near the surface. The events of group A were thought to follow a lightning stroke to ground and were reported to be seen in daytime.

The characteristics of these two groups do not generally conform to the relations obtained between parameters for the total set of the ball lightning descriptions. For example, in the total set the ball lightning originating following a stroke to ground tended to have a smaller than average diameter. The descriptions in group A, which also follow a stroke to ground, give a larger than average diameter. Another example concerns the ending of the event. For groups A and B, the ending is described as quiet. In the total set, those events described as first seen in midair (which would include group B) were more likely to end with a bang.

The probability of these two groups appearing merely by chance is impossible to evaluate, because the parameters are not independent. If they were independent, the probability of such sets occurring would be miniscule. As it is, sufficient interdependence could possibly be assumed to make these categories fortuitous.

The size of these groups individually, or even with both taken together, is such that extremely strong correlations herein would not generate very large values of X^2 for the total data set. For example, the two groups agree that the balls were larger than 15 inches (18 to 2) and were less bright than average (21 to 3). In the original set, these parameters were noncorrelated, as shown by a value of 0.1 for X^2. When the two subsets are removed, the remainder shows the very modest negative correlation of 2.3 for X^2.

CONCLUDING REMARKS

From the reports collected and described herein, the frequency of occurrence of a phenomenon which observers would label ball lightning is much greater than is commonly believed. It might even approach the order of magnitude of the frequency of lightning strokes to ground. Consequently, any postulated mechanism for these phenomena cannot be based on extremely rare and unusual circumstances.

There is little indication that ball lightning commonly involves large quantities of energy. Very bright, noisy or destructive occurrences were few. A mechanism for ball lightning need not account for megajoule energies to be satisfactory for the vast majority of cases.

Ball lightning commonly does not change in appearance during its existence. This fact makes it very difficult to propose a mechanism involving the dissipation of stored energy and tends to support a process involving a continuous energy supply from an external source. The radio-frequency excitation process proposed by Kapitza would agree well with the observed characteristics; unfortunately there is little evidence for the existence of sustained, intense, constant-frequency radiation associated with storms.

The steady discharge of atmospheric electricity might afford an explanation, but analysis to date has not provided a sufficiently detailed description. The basic problem here is that the major energy release should be located in the ball, a relatively good conductor, and not in the remainder of the atmospheric path.

The correlation of various parameters describing the events reported yielded few significant relations. The size, brightness, and duration were not strongly connected. Short duration events were more likely to end with a bang; they were also more likely to be connected with a lightning stroke to ground. The strong correlation between estimated ball diameter and distance from the observer probably reflects both a consistent observer error and a reduced observability for the smaller lightning balls at greater distances. Observer error may obscure some real relations among the ball lightning parameters but should not completely conceal them.

Among the 112 descriptions, two groups of 12 each were found which appeared to describe two different types of events. In group A, the ball lightning observations generally followed a lightning stroke to ground. The lightning ball was reported to end on or near the ground. In group B, the lightning ball was first seen in midair and remained in midair throughout its life. Both groups described balls that were not especially bright, although the size was estimated to be above the mean 15-inch diameter.

The precise mechanism by which lightning balls originate and are sustained has still not been elucidated. The analysis of a much larger number of descriptions, using the correlation techniques described herein, could provide significant information. In particular, if a number of basically different types of events are being called ball lightning such a study should identify them. Another approach that appears plausible is to obtain measurements of the significant parameters associated with one ball lightning event. These would include the spectrum of its visible radiation and the steady and time-varying atmospheric electric field in its vicinity. From the distribution of observations reported, a program of observation should have a reasonably good chance of acquiring such measurements in a period of 1 or 2 years.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 22, 1965.

APPENDIX A

PRELIMINARY QUESTIONNAIRE

The original preliminary questionnaire was as follows:

Your assistance is requested. By completing the following questionnaire you may help to bring about a better understanding of the relative frequency of occurrence of the various forms of lightning and also a better understanding of their mechanisms. This in turn might apply directly to plasma physics and energy storage work.

<u>DEFINITIONS</u>: <u>Ball Lightning</u> is the term used to describe a round, glowing object which may move slowly or hang in the air. It is thought to be associated with thunderstorms or ordinary lightning.

<u>Bead Lightning</u> is often described as appearing to be an ordinary stroke broken up into a string of glowing beads, or balls.

<u>Impact Point</u> of an ordinary stroke will be defined as the region within about 10 feet of the point which the lightning strikes. While everyone has seen ordinary lightning stretching from sky to ground, it is usually from a great distance. If you have seen a stroke so close that you would probably have noticed a persistent glowing ball near the ground, then answer question 1 "yes".

<u>QUESTIONS</u>:

1. Have you seen the impact point of ordinary lightning? ☐ yes, ☐ no
   How many times? ☐ 1, ☐ 2-3, ☐ 4-8, ☐ more than 8.

2. Have you seen bead lightning? ☐ yes, ☐ no
   How many times? ☐ 1, ☐ 2, ☐ 3, ☐ more than 3.

3. Have you seen ball lightning? ☐ yes, ☐ no
   How many times? ☐ 1, ☐ 2, ☐ 3, ☐ more than 3.

(The next 3 questions are to show whether you might have been more or less likely than the average person to have seen lightning phenomena.)

4. On the average, about how frequently have you been caught out of doors by a thunderstorm? ☐ 0-1, ☐ 2-3, ☐ 4-6, ☐ more than 6 times per year.

5. About how many thunderstorms per year might you have witnessed while in an automobile? ☐ 0-1, ☐ 2-3, ☐ 4-6, ☐ more than 6.

6. During a thunderstorm, would you:
   (a) prefer to watch the lightning displays?
   (b) prefer not to watch them?
   (c) have no preference?

7. Do you know the names and addresses of others who have witnessed either ball or bead lightning? yes, no
   If your answer is yes, please write them on the back of this page.

APPENDIX B

BALL LIGHTNING QUESTIONNAIRE

The original ball lightning questionnaire is reproduced with modifications below. The coding subsequently used for digital computer processing has been added and the number of responses inserted in the various blanks. The spaces originally provided to denote certainty, as shown in the samples, have been omitted.

The asterisks on the coding numbers indicate the later grouping of the responses into binary sets. Responses coded with a single asterisk were grouped into class a, those with double asterisks into class b. When no asterisks are present, the responses were not used in the binary groupings. A few questions permitted multiple responses. For these, as indicated in the coding, two card columns were employed. When such a question was unanswered, the code 0 appears in both columns.

BALL LIGHTNING   Name ____________________

Address ____________________

INTRODUCTION - This questionnaire is being sent to people reported to have seen ball lightning. They include those NASA personnel who answered the recent preliminary questionnaire as well as others whose names were obtained from the NASA people. From the reports of a large number of observers it is hoped that significant information about ball lightning can be extracted. Ball lightning seems to represent a stable arrangement of ionized gases and electric currents or a way of storing energy which has no satisfactory explanation at the present.

INSTRUCTIONS - You may help create an understanding of this phenomenon by filling out the attached form carefully. It is a lengthy one, for it includes almost everything that might be important.

If you've seen it more than once, please complete one form for your most detailed recollection. The completion of added forms for other events would be appreciated, but may be too much to ask.

If you don't like a question, or feel the choice of answers is too limited, please use the last sheet to add your comments. Identify the question by its number. Most of the questions are designed to be answered by a simple check mark for easier processing.

If you don't remember clearly and doubt the correctness of your answer, please mark your "best guess" and use the certainty scale at the right of each page to show your doubts. With no idea at all, check the "no idea" square. Very unsure answers should be marked 0-20%, very positive ones 80-100%, etc. The sample below shows how this may be done.

* SAMPLES *

	No idea	Certainty 0 20 40 60 80 100%
S21. Did you see the ball originate? _√_yes, ___no.		
S27. As it first appeared, its diameter was	☐	☐☐☐☐☑ (√ at 80-100)
0 2 4 6 8 √ 10 15 20 25 30 inches	☐	☐☐☐☒☐ (X at 60-80)
S41. The ball's nearest approach to a solid object was ___contact, ___0-1 ft, ___1-10 ft, ___10-100 ft, ___more	☒	☐☐☐☐☐

1. How many times have you seen ball lightning?
77 1, 17 2, 11 3, 1 4, 0 5-6, 3 more — 3 Not Answered

Col. 1, code 1* 2** 3** 4** 5** 6** 0

(Please complete one form for the event you remember in most detail. The completion of added forms for the other events would be appreciated.)

WHEN was this event observed?

2. During the year

...!....!....!....!....!....!....!....|!....!....!....!...
1910 '20 '30 '40 '50 '60

* ← | → **

Cols. 2 and 3 are the last two digits of the year

3. In the month of

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NA
0	0	0	3	7	28	35	18	4	2	1	0	14

* ← | → **

Cols. 4 and 5 are the two-digit number of the month

4. The time of day was

12 3 6 9 12 3 6 9 12
a.m. noon p.m.

** ← | ← * → | **

Cols. 6 and 7 are the two digits of the hour in 24-hour notation

5. Your age at the time of observation?

Age (years)	0–10	10–		20–		30–	40–	50–	60
Number	12	23	23	17	5	15	8	5	0
Col. 15 Code	1	2	3	4	5	6	7	8	9

WHERE did this occur?

6. State________________(or foreign country________________)
(not coded)

7. City________________(or if rural, ___miles from city)
(not coded)

8. The terrain in this area is best described as
67 flat, 22 rolling, 16 hilly, 5 mountainous. — 2 NA

Col. 8 Code 1* 2** 3** 4** 0

9. In the area nearest the ball lightning, the earth surface could best be described as

Col. 9 Code		
1*	8	water-covered
2*	6	barren
3*	23	meadow or brush
4*	16	wooded
5**	56	building covered
0	3	NA

10. Was your location
54 within a building, 14 a vehicle, 43 out-of-doors. 1 NA

Col. 10 Code 1* 2* 3** 0

11. With respect to ground level, were you
2 below ground, 93 near ground level, 11 second floor, 6 higher.

Col. 11 Code 1 2 3 4

12. How many others that you know of saw this ball lightning?
36 none, 32 1, 31 2-4, 8 more. 5 NA

Col. 12 Code 1* 2** 3** 4** 0

13. Did you observe it (check as many as apply)

Cols. 69 and 70

Code		
1*	13	through eyeglasses
2*	29	through window glass
3*	11	through a screen
4**	71	directly

CONDITIONS PRIOR TO OCCURRENCE

14. The ball appeared during which part of a storm?
28 early, 16 late, 47 middle, or 6 no storm connected. 15 NA

Col. 14 Code 1 2 3 4 0
(separate binary coding used for each category, 14a-14d)

15. If no storm at the time, how much of the sky was cloud-covered?
(replies not tabulated, too few cases)

16. Was the storm, if any, more violent than the average?
42 more violent, 48 average, 2 less violent, 5 no storm. 15 NA

Col. 16 Code 1* 2** 3** 4** 0

17. The rainfall just before the observation was
11 none, 16 slight, 24 medium, 38 heavy. 23 NA

Col. 17 Code 1* 2* 3** 4** 0

18. At the time, the wind velocity was about 48 NA

0–10	10–20	20–30	30–40	40–50	50–60	60 mph
10	19	13	13	7	1	1
1*	2*	3**	4**	5**	6**	7**

Col. 18 Code 1* 2* 3** 4** 5** 6** 7** 0

19. The direction from which the wind was blowing was 73 NA

N		E		S		W		N
	2	1	0	2	11	19	3	1

Col. 19 Code 2 3 4 5 6 7 8 1 0

20. Preceding your observation, was there any unusual amount of
dust or smoke in the air? 8 dust, 3 smoke, 62 none 39 NA

Col. 20 Code 1 2 3 0

FIRST APPEARANCE OF THE BALL LIGHTNING

21. Did you see the ball originate? 48 yes, 60 no 4 NA

Col. 21 Code 1* 2** 0

22. Did the appearance of the ball seem to follow a lightning stroke
62 to ground, 7 between clouds, 26 no stroke. 17 NA

Col. 22	Code	1*	2**	3**	0

23. IF the ball followed a stroke to ground, was the point of impact
1 water, 19 tree, 8 earth, 19 structure, or 18 power or telephone wires. 47 NA

Col. 23	Code	1*	2*	3*	4**	5**	0

24. When first seen, was the ball

Col. 24	Code		
	1*	6 among clouds	9 NA
	2*	55 in midair	Code 0
	3**	16 contacting metal	
	4**	12 contacting non-metal	
	5**	14 contacting ground	

25. The direction from you to the ball as first seen was

N	8		12	E	4		14	S	3		22	W	3		21	N	25 NA

Col. 25	Code	1	2	3	4	5	6	7	8	0

26. When you first saw it, its distance from you was
55 under 50 ft, 31 50-500 ft, 15 500 ft to 1/2 mi., 9 over 1/2 mi. 2 NA

Col. 26	1*	2**	3**	4**	0

27. As it first appeared, its diameter was about

Responses	1	8	7	9	12	13	23	15	10	14 NA
Scale	0	2	4	6	8	10	20	30	40 inches	

Col. 27	Code	1*2*3*4*5*	6*	7**	8**	9**	0

28. Its shape was 98 round, 9 elliptical, 3 ring-shaped, 2 other.

Col. 28	1*	2**	3**	4**

29. Check the best description of the ball's brightness.

Col. 29	Code		
	1*	12 As bright as an ordinary lightning stroke.	2 NA
	2*	23 Bright enough to illuminate nearby objects.	Code 0
	3**	66 Bright enough to be clearly visible in daylight.	
	4**	9 Bright enough to be barely visible in daylight.	

30. The ball appeared brightest

Col. 30	Code		
	1*	12 Near the outer surface	22 NA
	2*	10 Near the center.	Code 0
	3**	68 Uniformly all over.	

31. The color of the ball was (check location on spectrum)[a]

red	orange	yellow	green	blue	indigo	violet	white	
7	46	37	10	16	4	5	27	3 NA

Cols. 31 and 32	Code	1**	2*	3*	4**	5**	6**	7**	8**	0

a - Responses with double checks were tabulated for both; those circling a large section of the scale were assigned their mean.

DURING THE BALL'S EXISTENCE

32. How long did the ball last?

8	14	24	9	11	12	10	7	17 NA
0		5		10	15 20	25 30	35 40	45 seconds
Col. 42 Code 1*	2*	3*	4**	5**	6**	7**	8**	0

33. While you were watching, did the ball's size become
_5_ larger, _9_ smaller, _89_ remain about the same. 9 NA

Col. 33 Code 1 2 3 0

34. Did its brightness
_2_ increase, _12_ decrease, _91_ remain about the same 7 NA

Col. 34 Code 1 2 3 0

35. Did its appearance change noticeably?
If yes, please describe on last page. _7_ yes, _89_ no 16 NA

Col. 35 Code 1 2 0

36. Did you notice any sound from the ball? _[illegible]_ yes, _83_ no 4 NA

Col. 36 Code 1* 2** 0

37. Did you notice any odor from the ball? _23_ yes, _75_ no 14 NA

Col. 37 Code 1* 2** 0

38. Did you notice any sensation of heat?
If yes to any of these, please describe on last page
_4_ yes, _100_ no 8 NA

Col. 38 Code 1 2 0

39. The motion of the ball was mostly
_20_ vertical, _58_ horizontal, _20_ mixed, _10_ no motion 4 NA

Col. 39 1* 2** 3* 4* 0

40. Its closest approach to you was
_1_ contact, _2_ 0-1 ft, _32_ 1-10 ft, _3[illegible]_ 10-100 ft, _38_ over 100 ft. 1 NA

Col. 40 Code 1* 2* 3* 4** 5** 0

41. Its closest approach to any solid object was
_51_ contact, _13_ 0-1 ft, _19_ 1-10 ft, _8_ 10-100 ft, _11_ over 100 ft. 10 NA

Col. 41 Code 1* 2* 3** 4** 5** 0

42. Its maximum velocity appeared to be

30	20	3	3	3	12	41 NA
0	10	20	30	40 50	60 70 80 90 100 mph.	
Col. 43 Code 1*	2**	3**	4**	5**	6**	0

43. Its minimum velocity appeared to be

35	8	13	3	2	4	47 NA
0		10		20	30 40 mph.	
Col. 58 Code 1*	2**	3**	4**	5**	6**	0

44. Did the ball's movement seem to be guided by

Col. 44 Code			
1*	3	cloud layers	24 NA
2*	16	ground surface	Code 0
3*	12	power or telephone wires	
4*	6	other metal structure	
5**	34	no guide	
6*	17	other	

45. Did you have any impression of spinning or rotational movement within the ball? 35 yes, 61 no 16 NA

Col. 45 Code 1* 2** 0

46. During its lifetime, did the ball appear to pass through small apertures, screens, or solid objects?
If yes, please describe on last page. 24 yes, 77 no 11 NA

Col. 46 Code 1* 2** 0

47. If it made contact with any solid object, did it seem to be

Col. 47 Code			
1*	25	Surface contact with a metal object.	45 NA
2**	33	Surface contact with a non-metallic object.	Code 0
3*	1	Deeply penetrating contact with metal.	
4**	8	Deeply penetrating contact with non-metal.	

DISAPPEARANCE OF BALL

48. Was your last sight of the ball
71 as it disappeared or ended, 31 as it passed from your view. 10 NA

Col. 48 Code 1* 2** 0

49. Did the ball end 54 quietly, 24 explosively, 26 didn't see. 8 NA

Col. 49 Code 1* 2** 3 0

50. Did you notice any particular change in size, shape, brightness, color or velocity immediately before the ball ended?
If yes, please describe on last page. 11 yes, 82 no 19 NA

Col. 50 Code 1* 2** 0

51. Where was the ball when it disappeared?

Col. 51 Code			
1*	34	midair	14 NA
2**	23	on the ground	Code 0
3**	15	contacting metal	
4**	26	contacting non-metal	

52. How far from you was it when it disappeared?
20 under 10 ft, 31 10-50 ft, 20 50-200 ft, 30 over 200 ft. 11 NA

Col. 52 Code 1* 2* 3** 4** 0

53. Its velocity at termination was about
14 zero, 17 0-3 mph, 17 3-10 mph, 6 10-50 mph, 5 over 50 mph. 53 NA

Col. 53 Code 1* 2* 3** 4** 5** 0

AFTERMATH

54. Did the ball lightning have any aftereffects on (check as many as apply)[a]

Cols. 71 and 72 Code			
1*	9	metal structures	25 NA
2*	10	buildings	Code 0
3*	5	earth surface	
4*	5	people or animals	
5*	11	vegetation	
6**	55	none	

55. Was any unusual behavior noted concerning equipment such as radio, TV, hi-fi, car motors, etc. at about this time?

8 yes, 60 no 44 NA

Col. 55 Code	1	2	0

56. Was any photographic film found unexpectedly darkened after this event?

0 yes, 78 no 34 NA

Col. 56 Code	1	2	0

The responses pertaining to the degree of certainty the observer felt were distributed as follows:

No answer given	1254
"No idea" checked	754
Certainty, percent:	
0 tc 20	78
20 to 40	218
40 to 60	501
60 to 80	991
80 to 100	2476
Total	6272

APPENDIX C

REPORTS OF BALL LIGHTNING EVENTS

The descriptions of 112 ball lightning observations are listed in coded form in table IV. The code used is described in appendix B. The event numbers are arbitrary, except that when the same observer describes two events the second is given the initial digit 9. One observer provided three event descriptions: 1698, 9698, and 8698. Internal inconsistencies appear in a few descriptions. These have been left in the form originally provided.

TABLE V. - CODED DESCRIPTIONS OF 11[illegible] [illegible] EVENTS

Event	Column												
	5	10	15	20	25	30	35	40	45	50	55	58	60-62
1	22308	[illegible]	23 34	13330	11440	28133	4[illegible]	[illegible]	[illegible]	02212	420 0	213	[illegible]
2	[illegible]	18132	20 18	14003	23051	18133	30332	[illegible]	[illegible]	00212	213 2	212	[illegible]
3	11[illegible]07	1[illegible]331	23 33	[illegible]	11243	23133	30332	[illegible]	[illegible]	22132	24[illegible] 2	226	40[illegible]
5	1[illegible]110	11441	33 34	24203	11[illegible]38	1[illegible]141	23332	[illegible]	[illegible]	22112	424 0	01[illegible]	[illegible]
6	13108	21133	21 22	12100	12022	30130	20021	[illegible]	[illegible]	20121	14[illegible] 2	210	40[illegible]
7	1[illegible]211	21423	21 14	[illegible]302	113[illegible]1	37123	30222	[illegible]	[illegible]421	20112	243 0	013	40[illegible]
14	13306	141[illegible]	32 02	24000	21227	22130	23322	[illegible]	[illegible]	14112	123 2	211	[illegible]
16	12[illegible]08	13113	22 32	24200	11[illegible]31	16133	30330	[illegible]	11131	21121	221 2	011	400
18	63304	1[illegible]141	24 18	24000	20500	40420	[illegible]0032	[illegible]	[illegible]0000	21202	340 2	020	[illegible]
20	13200	[illegible]	24 22	23000	11024	09113	4[illegible]000	[illegible]	[illegible]100	00122	140 2	211	[illegible]
26	1[illegible]007	[illegible]	22 33	[illegible]003	11[illegible]0	28130	00332	[illegible]	[illegible]3022	20112	230 0	210	[illegible]
27	33304	[illegible]	22 23	[illegible]	212[illegible]0	17123	23332	[illegible]	1[illegible]021	22112	230 2	210	[illegible]
28	2[illegible]606	0[illegible]002	41 38	[illegible]4000	02010	30110	[illegible]0032	[illegible]	[illegible]001	10230	000 0	010	[illegible]
29	13200	00332	[illegible]	[illegible]0000	21230	27113	80332	[illegible]	[illegible]	22112	430 0	010	[illegible]
33	1200[illegible]	141[illegible]1	34 33	[illegible]	11241	14133	10332	[illegible]	[illegible]	22122	412 2	211	[illegible]
36	14306	16131	23 14	[illegible]	113[illegible]7	26133	[illegible]	[illegible]	[illegible]	22112	140 0	011	200
38	23107	1[illegible]131	20 24	[illegible]4000	21[illegible]	37133	1[illegible]332	[illegible]	10031	21112	240 0	010	200
39	13307	[illegible]	[illegible]	20000	20022	20130	00000	[illegible]	[illegible]0000	20030	000 0	010	100
41	0[illegible]607	23343	[illegible] 43	00000	23020	37143	[illegible]3332	[illegible]	[illegible]	20230	144 2	211	40[illegible]
42	13107	141[illegible]	[illegible] 32	[illegible]	1142[illegible]	40133	[illegible]3332	[illegible]	[illegible]002	22122	440 2	210	402
44	23[illegible]08	011[illegible]	[illegible] 34	[illegible]4000	2000[illegible]	14112	[illegible]3332	[illegible]	[illegible]002	11232	010 2	210	400
46	12106	[illegible]	[illegible]	[illegible]000	01420	23133	[illegible]	[illegible]	[illegible]0000	14220	430 1	210	402
49	12400	[illegible]	24 02	00000	20020	1[illegible]130	[illegible]	[illegible]	[illegible]	10120	112 2	211	10[illegible]
60	12[illegible]08	131[illegible]	[illegible]	23003	23027	06133	30332	[illegible]	[illegible]101	20112	113 2	012	40[illegible]
61	13408	13101	31 13	[illegible]103	23020	1[illegible]130	1[illegible]33[illegible]	[illegible]	[illegible]	00220	023 2	213	10[illegible]
62	13[illegible]07	123[illegible]3	[illegible]3 12	[illegible]303	22420	18123	[illegible]	[illegible]	[illegible]2	22132	[illegible] 2	211	40[illegible]
63	12[illegible]06	10231	33 12	[illegible]	13004	3[illegible]133	[illegible]	[illegible]	[illegible]102	21112	441 0	[illegible]	[illegible]
64	04[illegible]07	1[illegible]143	21 33	[illegible]3200	21220	23120	[illegible]	[illegible]	[illegible]	22122	420 0	210	[illegible]
65	12108	13233	22 33	[illegible]103	23020	26133	[illegible]332	[illegible]	[illegible]22	20112	100 2	023	[illegible]
67	12[illegible]08	1[illegible]233	[illegible]	0[illegible]000	23526	3[illegible]133	[illegible]330	[illegible]	[illegible]002	20102	140 0	010	100
68	13006	183[illegible]	23 33	[illegible]3323	11[illegible]21	14133	20332	[illegible]	[illegible]	20112	111 2	211	4014
69	14010	1[illegible]133	22 14	[illegible]003	13037	1[illegible]131	23330	[illegible]	1[illegible]031	21230	230 0	010	100
70	12107	184[illegible]3	21 1[illegible]	[illegible]103	21422	23133	203[illegible]	[illegible]	[illegible]2	20122	131 0	013	40[illegible]
77	2[illegible]30[illegible]	1712[illegible]	21 34	[illegible]4003	11444	28133	[illegible]	[illegible]	[illegible]72	22112	331 2	211	[illegible]
80	[illegible]07	221[illegible]1	21 32	[illegible]1003	2142[illegible]	10410	[illegible]0032	[illegible]	[illegible]	11230	320 0	210	40[illegible]
82	[illegible]000	00131	21 32	[illegible]000	11300	1[illegible]130	[illegible]332	[illegible]	11101	12112	412 1	001	40[illegible]
83	14300	221[illegible]1	21 3[illegible]	[illegible]4000	21[illegible]4[illegible]	12133	[illegible]	[illegible]	1[illegible]002	12230	120 0	210	10[illegible]
89	22[illegible]07	183[illegible]3	24 01	[illegible]000	21220	1[illegible]203	[illegible]332	[illegible]	00300	00000	000 0	010	40[illegible]
93	13800	1[illegible]313	20 01	[illegible]000	20020	16140	30330	[illegible]	[illegible]	20000	000 0	010	40[illegible]
102	14004	1[illegible]132	21 34	[illegible]003	11223	33133	2033[illegible]	[illegible]	[illegible]2	20122	430 0	210	[illegible]
104	14[illegible]00	005[illegible]1	34 01	00003	11220	20133	10332	[illegible]	[illegible]3002	20122	131 0	010	[illegible]
105	13006	10113	[illegible] 33	23200	20032	1[illegible]133	20332	[illegible]	[illegible]	21112	223 2	213	40[illegible]
109	1[illegible]004	24101	41 1[illegible]	10203	22027	13100	4[illegible]332	[illegible]	[illegible]1	20112	111 2	211	30[illegible]
116	1[illegible]07	14231	2[illegible]	[illegible]1203	21221	28123	20332	[illegible]	[illegible]	12030	000 0	010	204
119	1300[illegible]	[illegible]	[illegible] 33	23203	21241	14121	10332	[illegible]14	[illegible]	14112	220 2	210	40[illegible]
120	21300	18[illegible]	23 31	[illegible]4000	20030	12130	23302	[illegible]	10[illegible]0	11232	000 0	213	401
122	1620[illegible]	1614[illegible]	[illegible]	[illegible]3003	11[illegible]32	24133	[illegible]	[illegible]	[illegible]230	02121	443 2	214	[illegible]
125	16000	212[illegible]	20 07	20000	110[illegible]3	40133	[illegible]332	[illegible]	[illegible]022	00112	240 0	210	400
128	10[illegible]	1[illegible]131	[illegible]3 21	[illegible]3103	200[illegible]3	27131	[illegible]0332	[illegible]	[illegible]201	22232	244 2	213	400
133	13[illegible]08	1[illegible]213	[illegible] 03	00103	23027	20233	[illegible]3342	21[illegible]	30[illegible]1	20232	140 0	210	100
136	1[illegible]90[illegible]	1311	21 32	[illegible]	113[illegible]1	11123	10330	[illegible]	[illegible]21	22122	224 1	21[illegible]	303
142	16306	00117	[illegible] 34	[illegible]	21111	30132	[illegible]033[illegible]	[illegible]	[illegible]2	22112	440 2	210	10[illegible]
143	2[illegible]007	141[illegible]1	13 11	[illegible]1400	20020	16132	[illegible]0334	111[illegible]	[illegible]01	12122	314 0	012	3412
14[illegible]	13907	12431	23 3[illegible]	231[illegible]2	11427	34113	20302	[illegible]	[illegible]1	12212	243 2	210	400
14[illegible]	34003	1[illegible]1[illegible]3	21 34	[illegible]3	02021	3[illegible]13[illegible]	[illegible]0332	[illegible]	[illegible]201	20112	140 0	220	400

TABLE IV. - Concluded. CODED DESCRIPTIONS OF 112 BALL LIGHTNING EVENTS

Event	Column											
	5	10	15	20	25	30	35	40	45	50	55	60	65
151	34107	15242	22 34	13003	23013	40133	80322	22245	52002	00112	140 2	210	246
156	14005	10243	21 14	12373	11351	29231	34330	10245	32122	20110	242 0	211	403
166	13207	15131	21 3[illegible]	14373	21357	13131	20332	22223	23251	00212	222 2	202	136
167	23707	17251	22 12	12461	23035	12243	20232	22213	14132	24212	412 2	211	406
168	16205	11243	21 16	24203	21323	38132	30332	22215	00052	20232	140 2	210	100
169	34509	14253	21 12	22363	11527	22113	78332	22.34	40151	20112	132 2	211	406
170	15207	00323	21 02	22000	21432	16133	23332	21233	13152	14112	231 2	211	406
173	12400	15151	22 11	20003	11447	16133	23332	22233	14252	21112	112 2	212	406
178	15304	10012	43 44	41202	23020	29143	20322	22225	56252	20112	140 2	214	406
180	65505	24113	22 16	14763	13030	12123	67130	22244	16152	24111	321 2	211	406
181	12800	20122	23 31	14003	11553	17120	20332	20224	16250	22000	000 2	211	200
183	11706	16151	23 32	10000	11513	14113	80332	22233	11032	21112	310 2	210	406
184	13507	15253	21 23	00001	20020	17130	40300	20024	26141	20000	322 0	012	400
185	14707	14353	21 34	14273	13025	18133	80112	22223	33221	20230	013 0	013	406
187	15408	16131	41 34	14103	20420	28133	80332	22224	18132	21112	332 1	010	121
190	14806	20153	21 37	13371	21001	40312	23230	22235	53002	20132	140 0	220	400
410	23107	02151	23 32	14500	11531	17133	10332	20223	00022	21112	210 0	010	106
370	15809	17141	23 36	22273	11247	18333	40232	22244	16162	22112	421 1	211	20[illegible]
1391	04909	21143	12 16	21253	11225	37123	50332	22225	37162	22232	443 0	212	400
1610	36000	14133	21 37	20003	20527	23133	80332	12214	12032	21122	330 1	210	401
1614	13806	13151	22 31	23003	23025	25133	80332	22234	35002	20112	130 0	211	206
1618	64506	18133	23 36	13463	13026	26113	34330	11224	27422	12122	423 1	215	146
1620	10800	00232	23 31	24051	21225	14133	50332	22220	00050	20000	120 0	010	400
1645	16106	08333	21 16	22173	11221	12122	62111	12233	13161	12021	425 0	011	406
1662	14807	17151	22 06	00000	20045	17130	58332	22233	23140	21212	010 0	221	146
1670	11207	20153	24 12	21273	23021	17133	50321	22224	37242	20111	123 0	213	406
1691	12208	05151	22 37	23300	21433	12133	50332	12223	11002	21112	420 2	210	406
1698	35408	22132	22 33	14303	11423	27213	80332	22215	35141	21112	332 1	211	206
1704	14506	18151	32 33	23000	21425	17122	80332	22213	32251	20232	313 2	214	2014
1730	13505	18151	31 16	22003	01027	17130	30000	12223	25001	10232	100 2	220	406
1735	14000	20151	23 33	20003	20021	16133	20332	22223	14152	10032	412 2	211	406
1737	15007	21113	23 26	14473	22011	40220	67332	22225	58512	20030	000 0	026	400
1742	26207	17112	23 16	12003	11532	24123	80332	22245	13102	21112	331 2	211	406
1743	13007	18333	23 33	14263	20407	37123	23332	22225	47441	21122	144 2	210	402
1745	14400	022.1	31 02	10000	21227	10120	23002	22224	30000	00212	020 2	210	236
1746	15807	01142	22 44	41103	23023	29142	40132	22225	45061	20532	145 2	211	126
1747	12407	05131	22 32	14283	13025	19133	4.332	21224	13122	22221	422 2	211	20.
1749	34105	15143	21 17	12470	22027	49341	30322	22225	.3012	20212	14. 2	210	206
1763	14504	12151	23 43	41303	23051	18133	80332	12224	45622	24122	431 2	212	202
1800	14706	01151	21 20	23200	13013	40120	80332	2222.	[illegible]4312	20112	143 2	211	306
1801	15306	15352	22 32	13003	13027	10120	80332	22224	13031	21112	420 2	010	206
1809	12707	14353	23 21	24273	13041	28133	28332	12245	12100	02122	441 2	011	402
1845	16306	14151	42 13	31503	21221	16133	23332	21223	16652	14112	412 2	213	23[illegible]
8698	34007	12251	23 20	13401	21425	15131	23320	12223	13652	20112	110 2	211	406
9001	13506	20151	23 36	24023	23002	18123	20332	22222	00252	10232	125 0	213	240
9004	46206	19251	21 16	14511	13527	29121	23231	12234	18531	21121	222 0	211	303
9005	24908	17352	23 27	04263	13025	49231	20131	11225	13651	12121	340 0	010	2012
9006	10000	00151	22 20	22000	20004	17133	80002	22203	12002	12232	420 2	210	406
9027	33107	01340	22 33	23363	21220	27123	20332	11223	16061	12112	230 2	210	402
9044	25908	15151	22 18	24470	10055	15112	23332	21224	15022	22232	220 2	010	230
9077	24506	15121	22 01	00003	11335	14133	20332	22224	12261	21112	223 0	213	206
9089	24606	12123	24 05	00000	11530	26133	20332	20225	07032	21102	030 0	010	401
9106	13506	15153	22 23	14563	13526	37232	23231	21224	14622	21111	331 2	210	406
9167	24706	17251	32 14	12461	21447	13243	20232	22234	13152	22212	423 2	211	405
9169	34407	21251	33 22	13573	11247	15121	58232	22223	28651	12111	122 2	211	406
9410	23107	24151	11 31	14400	11431	17133	20332	20223	00020	21130	200 0	010	106
9698	34307	20251	23 20	34603	21437	15141	23320	12223	23042	24112	310 2	211	406

TABLE V. - [illegible] CORRELATIONS [illegible] BALL LIGHTNING

Parameter	[illegible] Total set	[illegible] Selected subset
Col. 22 - Ball followed lightning stroke to ground:		
Col. 24 - Ball first seen in midair(I)	3.2-	[illegible]-(I)
Col. [illegible] - Ball terminated in midair(I)	[illegible].8-	3.2-
Col. 41 - Approached within 1 ft of [illegible](I)	[illegible].0-	[illegible].2+
Col. 14a - [illegible] with a storm(I)	[illegible]-(I)	3.[illegible]-(I)
Col. 14c - Occurred in middle of storm	[illegible]+	4.[illegible]+
Col. [illegible] - Final velocity below 10 mph	4.[illegible]-	3.2-
Col. [illegible] - [illegible] aftereffects	4.3+	[illegible]+(I)
Col. [illegible] - Diameter less than 1[illegible] in.	4.1+	[illegible]+(I)
Col. 31 - Colors include orange or yellow	3.5+	3.6+
Col. [illegible] - Motion not only horizontal	3.[illegible]+	3.5-
Col. [illegible] - Approached within 10 ft of observer	1.8+	4.4+(I)
Col. 23 - [illegible] natural target:		
Col. [illegible] - [illegible] (not [illegible]) (I)	14.7-(I)	16.[illegible]-(I)
Col. [illegible] - [illegible] over natural terrain(I)	4.2+	[illegible]+(I)
Col. [illegible] - [illegible] through apertures, etc.	2.[illegible]+	7.3+(I)
Col. 24 - Ball first seen in midair:		
Col. [illegible] - [illegible] in midair (I)	1[illegible].7+(I)	[illegible]+(I)
Col. [illegible] - Approached within 1 ft of [illegible](I)	11.[illegible]-	11.[illegible]-(I)
Col. [illegible] - Ball [illegible] stroke to ground(I)	9.2-	[illegible]-(I)
Col. [illegible] - First seen within 10 ft of observer(I)	[illegible]-	[illegible]-
Col. [illegible] - [illegible] ball originate	[illegible].0-	1.[illegible]-
Col. [illegible] - Final velocity below 20 mph	[illegible]-	1.3+
Col. [illegible] - [illegible] seemed guided(I)	4.6-	1.9-
Col. [illegible] - [illegible] quietly	4.[illegible]-	3.2-
Col. [illegible] - First seen within 10 ft of observer:		
Col. [illegible] - [illegible] within 10 ft of observer(I)	[illegible].3-(I)	[illegible]1.0+(I)
Col. [illegible] - [illegible] within 10 ft of observer(I)	[illegible]+(I)	[illegible](I)
Col. [illegible] - [illegible] over natural terrain	1[illegible]-	[illegible]-
Col. 2[illegible] - Diameter less than 1[illegible] in.	9.3-	[illegible].3+
Col. 1[illegible] - Observer within [illegible]	[illegible].0+	1.3+
Col. 24 - First seen in midair (I)	7.[illegible]-	[illegible]-
Col. [illegible] - Approached within 1 ft [illegible]	[illegible]-	1.9+
Col. [illegible] - [illegible] ever saw ball end	[illegible]-	3.1-
Col. [illegible] - [illegible] in daytime	1.[illegible]-	4.1-
Col. 27 - Ball diameter less than 1[illegible] in.:		
Col. [illegible] - [illegible] within 10 ft of observer( )	13.6+	10.3+
Col. [illegible] - [illegible] within 10 ft of observer(I)	9.3+	[illegible].3+
Col. 41 - Approached within 1 ft of [illegible](I)	7.0+	7.0+
Col. 40 - [illegible] within 10 ft of observer(I)	6.1+	10.4-
Col. [illegible] - [illegible] through apertures, etc.(I)	[illegible].2+	[illegible]-(I)
Col. [illegible] - [illegible] through glass or screen	4.1-	2.1-
Col. [illegible] - [illegible] stroke to ground	4.1+	[illegible]+(I)
Col. [illegible] - [illegible]	3.3+(I)	[illegible].0+(I)
Col. [illegible] - [illegible] reporting [illegible]	0	4.[illegible]+
Col. [illegible] - [illegible] velocity under 20 mph	2.0-	4.[illegible]-
Col. 2[illegible] - [illegible]:		
Col. [illegible] - [illegible] during [illegible]	4.4-(I)	[illegible].4-(I)
Col. [illegible] - [illegible] has been only [illegible]	3.3-	3.1+(I)
Col. [illegible] - [illegible] under 1[illegible] in.	3.[illegible]+	[illegible].0+(I)
Col. 2[illegible] - [illegible] than average:		
Col. [illegible] - [illegible] daytime (I)	[illegible]-	[illegible]-
Col. [illegible] - [illegible] or rotating	3.[illegible]+	[illegible]+
Col. [illegible] - [illegible] through apertures, etc.	2.4+	4.[illegible]+
Col. 30 - [illegible] uniform:		
Col. 48 - [illegible] velocity under 10 mph	[illegible].0-	4.[illegible]-(I)
Col. [illegible] - [illegible] at end	3.[illegible]+	3.[illegible]+(I)
Col. [illegible] - [illegible] ball end	3.[illegible]-	3.3-
Col. [illegible] - Occurred late in storm	2.[illegible]-	3.[illegible]+
Col. 4[illegible] - [illegible] or rotating	2.[illegible]+	3.[illegible]
Col. 14[illegible] - [illegible] early in a storm:		
Col. [illegible] - [illegible](I)	[illegible]+	19.[illegible]
Col. 14c - Occurred in middle of storm (I)	3[illegible].0-(I)	[illegible].3-(I)
Col. 3[illegible] - Movement not only horizontal	7.3+	[illegible].6+(I)
Col. [illegible] - Occurred late in storm (I)	[illegible].3-(I)	[illegible].4-(I)
Col. [illegible] - [illegible] before 19[illegible]	2.0-	[illegible].2-
Col. 14[illegible] - [illegible] late in a storm:		
Col. 14c - Occurred in middle of storm (I)	1[illegible]-(I)	1[illegible].3-(I)
Col. 3[illegible] - Movement not only horizontal	[illegible]-(I)	[illegible].2-(I)
Col. [illegible] - Occurred before 19[illegible]	4.[illegible]+(I)	7.[illegible](I)
Col. 14a - Occurred early in storm (I)	[illegible].3-(I)	4.4-(I)
Col. [illegible] - [illegible]	3.[illegible]-(I)	[illegible]+(I)
Col. [illegible] - [illegible] through glass or screen	3.[illegible]-	2.[illegible]-(I)
Col. [illegible] - [illegible]	3.1-(I)	[illegible]-(I)
Col. [illegible] - [illegible]	[illegible]+	[illegible]
Col. [illegible] - [illegible]	1.0-	[illegible]-

[illegible]

[illegible]

TABLE IV. - Concluded. CODED DESCRIPTIONS OF 112 BALL LIGHTNING EVENTS

Event	Column 5	10	15	20	25	30	35	40	45	50	55	58	[illegible]
151	34407	15242	22 34	13003	23013	40133	80322	22245	52002	00112	140 2	210	246
156	14005	10243	21 14	12373	11351	29231	34330	10245	32122	20110	242 0	211	403
166	13207	15131	21 35	14373	21357	13131	20332	22223	23211	00212	222 2	202	136
167	23707	17551	22 12	12461	23035	12243	20232	22213	14132	24212	412 2	211	406
168	16205	11243	21 16	24203	21323	38132	30332	22215	00052	20232	140 2	210	100
169	34809	14253	21 12	22303	11527	22113	78332	22234	46151	20112	132 2	211	406
170	15207	00323	21 02	22000	21432	16133	23332	21233	13152	14112	231 2	211	406
173	12400	15151	22 11	20003	11447	16133	23332	22233	14222	21112	112 2	212	406
175	15304	19012	43 44	41202	23020	29143	20322	22225	[illegible]	20112	140 2	214	406
180	65408	24113	22 16	14763	13030	12123	67130	22244	16152	24111	321 2	211	406
181	12800	20122	23 33	14003	11453	17120	20332	20224	16210	22000	000 2	211	200
183	11706	18151	23 32	10000	11513	14113	80332	22233	11032	21112	310 2	210	406
184	13507	15213	21 23	00001	20020	17130	40300	20024	26141	20000	322 0	012	400
185	14707	14353	21 34	14273	13025	18133	80112	22223	33221	20230	013 0	013	406
187	15408	16131	41 34	14103	20420	28133	80332	22224	18132	21112	332 1	010	121
190	14806	20153	21 37	13371	21001	40312	23230	22235	53002	20132	140 0	220	400
410	23107	02151	23 32	14500	11531	17133	10332	20223	00022	21112	210 0	010	106
970	15509	17141	23 36	22273	11247	18333	45232	22244	16162	22112	421 1	211	20[illegible]
1351	04909	21143	12 16	21253	11225	37123	50332	22225	37162	22232	443 0	212	400
1610	36000	14133	21 37	20003	20527	23133	80332	12214	12032	21122	330 1	210	401
1614	13806	13151	22 31	23003	23025	28133	80332	22234	31002	20112	130 0	211	206
1618	64506	18133	23 36	13463	13026	26113	34330	11224	27422	12122	423 1	21[illegible]	146
1620	10800	00232	23 31	24051	21225	14133	50332	22220	00050	20000	120 0	010	400
1645	16106	08333	21 16	22173	11221	12122	62111	12233	13161	12021	42[illegible] 0	011	406
1662	14807	17151	22 06	00000	20045	17130	58332	22233	23140	21212	010 0	221	146
1670	11207	20153	24 12	21273	23021	17133	50321	22224	37242	20111	123 0	213	406
1691	12208	05151	22 37	23300	21433	12133	50332	12223	11002	21112	420 2	210	406
1698	35408	22132	22 33	14303	11423	27213	80332	22215	35141	21112	332 1	211	206
1704	14506	18151	32 33	23000	21425	17122	80332	22213	32251	20232	313 2	214	2014
1730	13505	15151	31 16	22003	01027	17130	30000	12223	25001	10232	100 2	220	406
1735	14000	20151	23 33	20003	20021	16133	20332	22223	14152	10032	412 2	211	406
1737	15007	21113	23 26	14473	22011	40220	67332	22225	[illegible]	20030	000 0	026	400
1742	26707	17112	23 16	12003	11532	24123	80332	22245	15102	21112	331 2	211	406
1743	13007	18333	23 33	14263	20407	37123	23332	22225	47441	21122	141 2	210	402
1745	14400	02251	31 02	10000	21227	10120	23002	22224	30000	00212	020 2	210	236
1746	15807	01142	22 44	41103	23023	29142	45132	22225	48001	20232	14[illegible] 2	211	126
1747	12407	05131	22 32	14253	13028	19133	45332	21224	13122	22221	422 2	211	20[illegible]
1749	34108	15143	21 17	12470	22027	49341	30322	22225	53012	20212	14[illegible] 2	216	206
1763	14804	12151	23 43	41303	23051	18133	80332	12224	45622	24122	431 2	212	202
1800	14706	01151	21 20	23200	13013	40120	80332	22225	54312	20112	143 2	211	306
1801	15306	15352	22 32	13003	13027	10120	80332	22224	13031	21112	420 2	010	206
1809	12707	14353	23 21	24273	13041	26133	28332	12245	12100	02122	441 2	011	402
1845	16306	14151	42 13	31503	21221	16133	23332	21223	16612	14112	412 2	213	23[illegible]
8698	34007	12251	23 20	13401	21425	15131	23320	12223	13612	20112	110 2	211	406
9001	13506	20151	23 36	24023	23002	18123	20332	22222	00212	10232	123 0	213	240
9004	46206	13251	21 16	14511	11527	29121	23231	12234	18531	21121	222 0	211	303
9005	24308	17352	23 2[illegible]	04263	13025	49231	20131	11225	13611	12121	340 0	010	2012
9006	10000	00151	22 20	22000	20004	17133	80002	22203	12002	12232	420 2	210	406
9027	33107	01340	22 33	23303	21220	27123	20332	11223	16061	12112	230 2	210	402
9044	25308	15151	22 18	24470	10055	15112	23332	21224	15022	22232	220 2	010	230
9077	24506	15121	22 01	00003	11335	14133	20332	22224	12261	21112	223 0	213	206
9083	24606	12123	24 05	00000	11530	26133	20332	20225	07032	21102	030 0	010	401
9106	13506	15153	22 25	14563	13526	37232	23231	21224	14622	21111	331 2	210	406
9167	24706	17251	32 14	12461	21447	13243	20232	22234	13152	22212	423 2	211	40[illegible]
9169	34407	21251	33 22	13573	11247	15125	58232	22223	22611	12111	122 2	211	406
9410	23107	24151	11 31	14400	11431	17133	20332	20223	00020	21130	200 0	010	106
9698	34307	20251	23 20	34603	21437	15141	23320	12223	23042	24112	310 2	211	406

APPENDIX D

POSSIBLY MEANINGFUL CORRELATIONS

The ball lightning observation parameters in their grouped or binary form produced many correlations of possible significance. The total set of observations was first correlated and examined. Then in an attempt to evaluate some of the weaker correlations, the calculation was repeated omitting all answers with a low value (less than 40 percent) of the associated certainty parameter. This involved the omission of about one-sixth of the answers on the average.

In table V are listed all the correlations that produced a value of X^2 of 4.0 or greater either for the total set or for the selected subset. Also included are those producing a X^2 exceeding 2.7 for both sets. Since these values of X^2 correspond to a probability of chance occurrence of 0.0455 and 0.10, respectively, it should be obvious that many of the tabulated correlations may be without significance. The total number of correlations involving the 46 parameters is 1035. Chance alone should thus give rise to one with X^2 as great as 11.0 (corresponding to a probability of about 0.001.) The inclusion of a correlation should not be taken as proof of a nonchance relation; however, these correlations may suggest models for the ball lightning process as well as aiding in the evaluation of existing models.

Certain parameters are obviously related and should yield large values of X^2. When the observed correlation is of the same sense as might be expected, the symbol P is used. The sense of the correlation is shown by plus or minus signs, which indicate whether the two parameters occur more often together or separately. The symbol I denotes cases where the population of one block of the array falls below five. In such cases, the interpretation of X^2 in terms of probability becomes less rigorous and the relation suggested becomes more tentative.

The parameters (columns) are described in condensed phrases. Reference to appendix B will provide an exact definition of the categories involved.

TABLE V. - CORRELATIONS AMONG PARAMETERS DESCRIBING BALL LIGHTNING

Parameter	χ^2 Total set	χ^2 Selected subset
Col. 1 - Events reported by observers of only one occurrence:		
Col. 18 - Wind velocity under 20 mph	17.8+(I)[a]	7.7+(I)
Col. 16 - Occurred in extra-violent storm	9.0-	4.0-
Col. 28 - Round shape	3.3+	3.1+(I)
Col. 2 - Occurrences before 1950:		
Col. 9 - Occurred over natural terrain	11.4-	7.0-
Col. 39 - Motion not only horizontal	5.8-	5.8-
Col. 12 - No other observers known	5.6-	3.1-
Col. 69 - Viewed through glass or screen	5.5-	5.0-
Col. 51 - Terminated in midair	5.1+	6.1+(I)
Col. 14b - Occurred late in storm	4.9+(I)	7.7+(I)
Col. 14d - Unconnected with a storm	4.4-(I)	3.6-(I)
Col. 14a - Occurred early in storm	2.0-	5.2-
Col. 4 - Occurrences in pre-July months:		
Col. 6 - Seen in daytime	5.9+(I)	4.5+(I)
Col. 31 - Colors include orange or yellow	3.5+	3.3+
Col. 14b - Occurred late in storm	3.1-(I)	6.0-(I)
Col. 8 - Occurred over flat terrain	2.8+	3.1+
Col. 6 - Events occurring in daytime:		
Col. 29 - Brighter than average	8.4-	0.9-
Col. 4 - Occurred in pre-July months	5.9+(I)	4.5+(I)
Col. 40 - Approached within 10 ft of observer	4.6-	4.5-
Col. 39 - Motion not only horizontal	4.0+	0.7+
Col. 50 - Appeared to be changing at end	2.7-	4.5-
Col. 26 - First seen within 50 ft	1.9-	4.1-
Col. 8 - Occurrences over flat terrain:		
Col. 69 - Viewed through glass or screen	6.9+	6.3+
Col. 10 - Observed from within building or vehicle	4.8+	3.2+
Col. 31 - Colors include orange or yellow	4.1-	5.2-
Col. 52 - Ended within 50 ft of observer	4.0+	2.4+
Col. 4 - Occurred in pre-July months	2.8+	3.1+
Col. 9 - Occurrences over neutral terrain:		
Col. 40 - Approached within 10 ft of observer	17.1-	10.1-
Col. 52 - Ended within 50 ft of observer	17.0-	7.2-
Col. 26 - First seen within 50 ft of observer	15.7-	9.9-
Col. 2 - Occurred before 1950	11.4-	7.0-
Col. 18 - Wind velocity below 20 mph	7.1+	2.9+
Col. 46 - Passed through apertures, etc	4.8-	2.1-(I)
Col. 23 - Followed stroke impacting natural target	4.2+	1.8+(I)
Col. 51 - Ended in midair	2.5-	4.8-
Col. 10 - Events observed from within building or vehicle:		
Col. 69 - Viewed through glass or screen(P)[b]	24.3+	29.0+(I)
Col. 40 - Approached within 10 ft of observer	15.4+(I)	4.5+(I)
Col. 52 - Terminated within 50 ft of observer	11.9+	3.4+
Col. 41 - Approached within 1 ft of solid	8.1+	3.1+
Col. 26 - First seen within 50 ft of observer	8.0+	1.3+
Col. 8 - Occurred over flat terrain	4.8+	3.2+
Col. 17 - Rainfall slight or none	4.0-	0.8-
Col. 49 - Ended quietly	2.8+	4.3+
Col. 14b - Occurred late in storm	1.0-	1.5-
Col. 48 - Observed ball end	2.3-	4.2-(I)
Col. 12 - Events seen only by reporting observer:		
Col. 2 - Occurred before 1950	5.6-	3.1-
Col. 42 - Duration less than 6 sec(P)	3.3+	6.8+
Col. 27 - Diameter less than 15 in.	0.0	4.8+(I)
Col. 16 - Occurrences during storms of above-average violence:		
Col. 18 - Wind velocity below 20 mph(P)	10.5-	2.8-(I)
Col. 1 - Observer has seen only once	9.0-	4.0-
Col. 21 - Observer saw ball originate	4.3+	1.2+
Col. 28 - Round shape	4.4-(I)	1.4-(I)
Col. 14d - Unconnected with a storm(P)	4.3-(I)	3.9-(I)
Col. 17 - Occurrences while rainfall slight or none:		
Col. 14a - Occurred early in storm[b](P)	29.2+	19.0+
Col. 14c - Occurred in middle of storm(P)	25.2-(I)	15.8-(I)
Col. 14d - Unconnected with a storm(P)	4.0+(I)	5.5+(I)
Col. 10 - Observer within building or vehicle(P)	4.0-	0.8-
Col. 18 - Wind velocity less than 20 mph:		
Col. 1 - Observer has seen only once	17.8+(I)	7.7+(I)
Col. 16 - Storm extra-violent(P)	10.5-	2.8-(I)
Col. 9 - Occurred over natural terrain	7.1+	2.9+
Col. 24 - First seen in midair	5.5+	1.3+
Col. 40 - Approached within 10 ft of observer	5.4-(I)	6.0-(I)
Col. 22 - Followed a stroke to ground	4.9-	3.2-
Col. 27 - Diameter under 15 in.	2.0-	4.5-
Col. 21 - Observer saw ball originate:		
Col. 50 - Appeared to be changing at end	9.6+(I)	7.3+(I)
Col. 48 - Observer saw ball end	7.6+	4.9+(I)
Col. 51 - Ball ended in midair	7.2-	2.5-
Col. 24 - First seen in midair	7.0-	1.9-
Col. 40 - Approached within 10 ft of observer	4.8-	5.8-
Col. 16 - Extra-violent storm	4.3+	1.2+
Col. 58 - Minimum velocity under 4 mph	3.5+	3.3+

[a] I denotes insufficient data.

[b] P denotes predictable correlation.

TABLE V. - [illegible] CORRELATIONS [illegible] BALL LIGHTNING

Parameter	[illegible]	
	Total set	Selected subset
Col. 22 - [illegible] ground:		
Col. [illegible] - [illegible] first seen [illegible] ([illegible])	3.2-	[illegible]-( )
Col. [illegible] - [illegible] ([illegible])	[illegible]-	3.2-
Col. [illegible] - [illegible] within 1 ft of [illegible] ([illegible])	[illegible]	[illegible]+
Col. 14[illegible] - [illegible] with [illegible] (i)	[illegible]-( )	[illegible]-( )
Col. 14[illegible] - [illegible] in middle of storm	[illegible]+	[illegible]+
Col. [illegible] - [illegible] velocity below [illegible]	4.[illegible]-	3.[illegible]-
Col. [illegible] - [illegible] aftereffects	4.3-	3.[illegible]+(i)
Col. [illegible] - Diameter less than 1[illegible] in.	[illegible]-	3.[illegible]+(i)
Col. 2[illegible] - [illegible] include orange or yellow	[illegible]-	3.[illegible]+
Col. [illegible] - [illegible] not only [illegible]	3.[illegible]+	3.5+
Col. [illegible] - Approached within 10 ft of observer	1.[illegible]+	4.1-(i)
Col. 23 - [illegible] natural [illegible]:		
Col. [illegible] - [illegible] ([illegible]) ( )	14.7-(i)	[illegible]-(i)
Col. [illegible] - [illegible] natural [illegible] ( )	4.2+	[illegible]-(i)
Col. [illegible] - [illegible] apertures, [illegible]	2.7+	3.3+(i)
Col. 24 - [illegible] seen in midair:		
Col. [illegible]1 - [illegible] midair ([illegible])	[illegible].7+(i)	3.7+(i)
Col. [illegible] - [illegible] within 1 ft [illegible] ( )	11.[illegible]-	11.[illegible]-(i)
Col. [illegible] - [illegible] ground(i)	8.[illegible]-	[illegible]-(i)
Col. [illegible] - [illegible] within 10 ft of observer(i)	[illegible]-	[illegible]-
Col. [illegible] - [illegible] ball [illegible]	[illegible].0-	[illegible]-
Col. [illegible] - [illegible] velocity below 20 mph	[illegible]+	1.3-
Col. [illegible] - [illegible] ([illegible])	4.[illegible]-	1.5-
Col. 4[illegible] - [illegible]	4.[illegible]-	3.[illegible]-
Col. [illegible] - [illegible] within 10 ft of observer:		
Col. [illegible] - [illegible] within 10 ft of observer ( )	[illegible].3+(i)	[illegible]-( )
Col. [illegible] - [illegible] within 10 ft of observer( )	[illegible].[illegible]+(i)	[illegible].4+(i)
Col. [illegible] - Observer [illegible]	[illegible]-	[illegible]-
Col. 2 - Diameter less than 1[illegible] in.	[illegible].3+	[illegible].3+
Col. 1[illegible] - Observer within [illegible]	[illegible].0+	1.3+
Col. 24 - First seen in midair ([illegible])	7.[illegible]-	7.[illegible]-
Col. [illegible] - approached within 1 ft of [illegible]	[illegible]+	1.3+
Col. 4[illegible] - Observer saw ball end	3.[illegible]-	3.1-
Col. [illegible] - [illegible]	[illegible]-	4.[illegible]-
Col. [illegible] - [illegible] diameter less than 1[illegible] in.:		
Col. [illegible] - [illegible] within 10 ft of observer(i)	1[illegible].[illegible]+	10.3+
Col. [illegible] - First seen within 10 ft of observer( )	[illegible].3+	[illegible].3+
Col. [illegible]1 - [illegible] within 1 ft of [illegible](i)	7.0+	[illegible].0+
Col. 4[illegible] - [illegible] within 10 ft of observer(i)	[illegible]+	10.[illegible]-
Col. [illegible] - [illegible] through apertures, [illegible](i)	[illegible].2+	[illegible]+(i)
Col. [illegible] - [illegible] through glass or [illegible]	[illegible].1-	2.1-
Col. [illegible] - [illegible] struck [illegible]	[illegible].1+	[illegible]+(i)
Col. [illegible] - [illegible] shape	3.3+(i)	7.0+(i)
Col. [illegible] - Seen only by [illegible]	0	4.5+
Col. [illegible] - [illegible] velocity under 20 mph	2.[illegible]-	4.[illegible]-
Col. [illegible] - [illegible] shape:		
Col. [illegible] - [illegible] during [illegible]	4.4-(i)	[illegible].4-(i)
Col. 1 - [illegible] only [illegible]	2.3+	5.1+(i)
Col. [illegible] - Diameter under 1[illegible] in.	3.3+	[illegible].0+( )
Col. [illegible] - [illegible] than average:		
Col. [illegible] - [illegible] (i)	[illegible]-	0.[illegible]-
Col. 4[illegible] - [illegible] or rotating	3.3+	[illegible]+
Col. [illegible] - [illegible] through apertures, [illegible]	2.[illegible]+	4.[illegible]+
Col. 2[illegible] - [illegible] uniform:		
Col. 4[illegible] - [illegible] velocity under [illegible]	[illegible]-	4.[illegible]-(i)
Col. [illegible] - [illegible] ball	3.[illegible]+	[illegible]+(i)
Col. [illegible] - [illegible] end	3.[illegible]-	[illegible].3-
Col. 14[illegible] - [illegible] late in storm	2.[illegible]+	3.[illegible]+
Col. 4[illegible] - [illegible] or rotating	[illegible]-	[illegible]+
Col. 14[illegible] - [illegible] early in [illegible] storm:		
Col. [illegible] - [illegible] ([illegible])	[illegible].1+	19.[illegible]-
Col. 14[illegible] - [illegible] in middle of storm (i)	3[illegible].0-(i)	2[illegible]-( )
Col. [illegible] - [illegible] not only [illegible]	[illegible].3+	[illegible]+( )
Col. [illegible] - [illegible] late in storm( )	[illegible].3-(i)	4.4-( )
Col. [illegible] - [illegible] before 19[illegible]	2.[illegible]-	[illegible]-
Col. 14[illegible] - [illegible] late in a storm:		
Col. 14[illegible] - [illegible] in middle of storm ( )	1[illegible].4-(i)	1[illegible]-(i)
Col. [illegible] - [illegible] not only [illegible]	[illegible]-(i)	[illegible]-( )
Col. [illegible] - [illegible] before 19[illegible]	4.[illegible]+(i)	[illegible]+( )
Col. 14[illegible] - [illegible] early in storm( )	[illegible]-(i)	4.4-( )
Col. [illegible] - [illegible]	2.0+(i)	3.[illegible]( )
Col. [illegible] - [illegible]	[illegible]-	3.[illegible]-( )
Col. [illegible] - [illegible]	3.1-(i)	[illegible]-( )
Col. [illegible] - [illegible]	[illegible]+	[illegible]
Col. [illegible] - [illegible]	1.[illegible]-	[illegible]-

[illegible]

[illegible] correlation.

TABLE V. - Continued. CORRELATIONS AMONG PARAMETERS DESCRIBING BALL LIGHTNING

Parameter	χ^2	
	Total set	Selected subset
Col. 14c - Occurred in middle of storm:		
Col. 14a - Occurred early in storm(P)[b]	37.0-(I)	26.[illegible]-(I)[a]
Col. 17 - Slight or no rainfall(P)	2[illegible].2-(I)	1[illegible]-(I)
Col. 14b - Occurred late in storm(P)	13.4-(I)	1[illegible]-(I)
Col. 14d - Unconnected with a storm(P)	6.0-(I)	3.9-(I)
Col. 22 - Followed stroke to ground	[illegible].6+	4.[illegible]+
Col. 50 - Appeared changing at end	3.8-(I)	4.1-(I)
Col. 14d - Occurrences unconnected with a storm:		
Col. 22 - Followed a stroke to ground(P)	[illegible].6-(I)	3.0-(I)
Col. 42 - Duration less than 6 sec	6.2-(I)	3.4-(I)
Col. 52 - Ended within 50 ft of observer	5.7-(I)	3.2-(I)
Col. 14c - Occurred in middle of storm(P)	6.0-(I)	3.9-(I)
Col. 2 - Occurred before 1950	4.4-(I)	3.6-(I)
Col. 16 - Occurred in extra violent storm(P)	4.3-(I)	3.9-(I)
Col. 17 - Slight or no rainfall(P)	4.0+(I)	[illegible]+(I)
Col. 31 - Colors including orange or yellow:		
Col. 8 - Occurred in flat terrain	4.1-	[illegible].2-
Col. 4 - Occurred in pre-July month	3.[illegible]+	3.3+
Col. 22 - Followed stroke to ground	3.3+	3.6+
Col. 41 - Approached within 1 ft of solid	2.9+	3.[illegible]+
Col. 36 - Events accompanied by sound:		
Col. 49 - Ended quietly(P)	1[illegible]-(I)	13.9-(I)
Col. 42 - Duration less than 6 sec	4.6+	4.6+
Col. 48 - Observed ball end	4.2+(I)	[illegible]+(I)
Col. 71 - Had aftereffects(P)	4.2+	1.9+
Col. 37 - Events accompanied by an odor:		
Col. 46 - Passed through apertures, etc.	8.8+	14.3+(I)
Col. 71 - Had aftereffects(P)	6.0+	7.1+(I)
Col. 49 - Ended quietly	4.5-	2.2-
Col. 48 - Observed ball end	3.9-	2.7-
Col. 40 - Approached within 10 ft of observer(P)	3.[illegible]+	[illegible].4+
Col. 39 - Motion of ball not predominantly horizontal:		
Col. 43 - Maximum velocity under 10 mph	9.8+	2.2+
Col. 14a - Occurred early in storm	7.3+	9.6+(I)
Col. 14b - Occurred late in storm	6.8-(I)	6.2-(I)
Col. 58 - Minimum velocity under 4 mph	6.8+	2.6+
Col. 2 - Occurred before 1950	5.8-	5.8-
Col. 6 - Seen in daytime	4.0+	0.7+
Col. 22 - Followed stroke to ground	3.2+	3.3+
Col. 40 - Ball approached within 10 ft of observer:		
Col. 26 - First seen within 50 ft of observer(P)	44.6+(I)	29.4+(I)
Col. 52 - Ended within 50 ft of observer(P)	31.1+(I)	18.5+(I)
Col. 46 - Passed through apertures, etc.	17.4+	12.7+(I)
Col. 3 - Occurred over natural terrain	17.1-	10.1-
Col. 10 - Observer within building or vehicle	15.4+	4.[illegible]+(I)
Col. 41 - Approached within 1 ft of solid(P)	6.8+	3.2+
Col. 27 - Diameter under 15 in.	6.1+	10.4+
Col. 18 - Wind velocity under 20 mph	[illegible].4-(I)	6.0-(I)
Col. 21 - Observer saw ball originate	4.8-	[illegible].8-
Col. 6 - Seen in daytime	4.6-	4.[illegible]-
Col. 37 - Accompanied by odor(P)	3.5+	[illegible].4+
Col. 48 - Observer saw ball terminate	3.3-	[illegible].7-
Col. 22 - Followed stroke to ground	1.8+	4.4+(I)
Col. 41 - Ball came within 1 ft of solid object:		
Col. 51 - Ball terminated in midair(P)	28.0-	19.1-
Col. 24 - First seen in midair(P)	11.[illegible]-	11.6-(I)
Col. 10 - Observer in building or vehicle	9.1+	3.1+
Col. 22 - Followed stroke to ground	8.0+	7.2+
Col. 52 - Ball terminated within 50 ft of observer	8.0+	3.7+
Col. 46 - Passed through apertures, etc.(P)	7.6+	4.8+(I)
Col. 27 - Diameter less than 15 in.	7.0+	7.0+
Col. 40 - Approached within 10 ft of observer(P)	6.5+	3.2+
Col. 26 - First seen within 50 ft of observer	[illegible].7+	1.9+
Col. 44 - Motion seemed guided(P)	4.0+	2.1+
Col. 31 - Colors included orange or yellow	2.9+	3.[illegible]+
Col. 50 - Was changing at end	2.0+(I)	4.2+(I)
Col. 42 - Duration of observed ball less than 6 sec:		
Col. 14d - Not connected with a storm	6.2-(I)	3.4-(I)
Col. 36 - Accompanied by sound	4.6+	4.6+
Col. 49 - Ended quietly	3.6-	4.0-
Col. 12 - No other observers	3.3+	6.8+
Col. 43 - Maximum velocity under 10 mph:		
Col. 58 - Minimum velocity under 4 mph(P)	27.5+(I)	24.6+(I)
Col. 53 - Final velocity under 3 mph(P)	17.9+	9.9+(I)
Col. 39 - Motion not only horizontal	9.8+	2.2+
Col. 30 - Brightness nonuniform	6.6-	4.9-(I)
Col. 44 - Motion of ball seemed guided		
Col. 51 - Ended in midair(P)	17.1-	9.6-
Col. 47 - Contacted metal(P)	6.1+(I)	3.7+(I)
Col. 24 - First seen in midair(P)	4.6-	1.9-
Col. 46 - Passed through apertures, etc.	4.6-	[illegible].3-
Col. 41 - Approached within 1 ft of solid(P)	4.0+	[illegible].1+

[a](I) denotes insufficient data.

[b](P) denotes predictable correlation.

TABLE V. - Concluded. CORRELATIONS AMONG PARAMETERS CONCERNING BALL LIGHTNING

Parameter	χ^2 Total set	χ^2 Selected subset
Col. 4 - Ball seemed to be spinning or rotating:		
Col. 28 - Brighter than average	3.3+	7.8+
Col. 30 - Brightness nonuniform(P)[b]	2.8+	3.0+
Col. 48 - Ball passed through apertures, solids, etc:		
Col. 40 - Approached within 10 ft of observer(P)	17.4+	12.7+(I)[a]
Col. 37 - With odor	8.5+	14.3+(I)
Col. 41 - Approached within 1 ft of solid(P)	7.6+(I)	4.8+(I)
Col. 42 - Ended within 50 ft of observer(P)	6.1+	4.7+(I)
Col. 27 - Diameter under 15 in.	5.2+	7.7+(I)
Col. 45 - Observer saw ball terminate(P)	5.0-	3.0-
Col. 9 - Occurred on natural terrain(P)	4.5-	2.1-(I)
Col. 44 - Motion seemed guided	4.6-	2.3-
Col. 47 - Contacted metal	4.3-(I)	0.8-(I)
Col. 23 - Stroke impacted natural target	2.7+	3.3+(I)
Col. 29 - Brighter than average	2.4+	4.7+
Col. 47 - Ball contacted metal (not nonmetal):		
Col. 23 - Stroke impacted natural target(P)	14.7-(I)	10.6-(I)
Col. 44 - Motion seemed guided	6.1+(I)	3.7+(I)
Col. 48 - Passed through apertures, etc.	4.3-(I)	0.5-(I)
Col. 45 - Observer saw ball end:		
Col. 13 - Final velocity under 3 mph	[illegible].3+(I)	7.8+(I)
Col. 21 - Observer saw ball originate	7.6+	4.9+(I)
Col. 48 - Passed through apertures, etc.	[illegible].0-	3.0-
Col. 36 - Accompanied by sound	4.2+(I)	[illegible].5+(I)
Col. 37 - Accompanied by odor	3.9-	2.7-
Col. 30 - Brightness nonuniform	3.[illegible]-	3.3-
Col. 40 - Approached within 10 ft of observer	3.3-	[illegible].7-
Col. 26 - First seen within 50 ft of observer	3.2-	3.1-
Col. 10 - Observed from building or vehicle	[illegible].3-	4.2-(I)
Col. 43 - Ball ended quietly:		
Col. 36 - Accompanied by sound(P)	1[illegible]-	13.9-(I)
Col. 71 - Had aftereffects(P)	14.6-	13.7-
Col. 50 - Was changing at end	7.5-(I)	4.6-(I)
Col. 37 - Accompanied by odor	4.5-	2.2-
Col. 24 - First seen in midair	4.6-	3.2-
Col. 12 - Duration less than 6 sec	3.6-	4.0-
Col. 10 - Observed from within building or vehicle	2.8+	4.3+
Col. 50 - Ball appeared to be changing at the end:		
Col. 21 - Observer saw ball originate	9.0+(I)	7.3+(I)
Col. 43 - Ended quietly	7.3-(I)	4.6-(I)
Col. 14b - Occurred in middle of storm	3.8-(I)	4.1-(I)
Col. 14 - Occurred late in storm	5.6+(I)	3.8+(I)
Col. 30 - Brightness nonuniform	5.3+	3.6+(I)
Col. 8 - Seen in daytime	[illegible].7-	4.[illegible]-
Col. 41 - Came within 1 ft of solid	[illegible].0+(I)	4.2-(I)
Col. 51 - Ball ended in midair:		
Col. 41 - Approached within 1 ft of solid(P)	24.0-	19.1-
Col. 44 - Motion seemed guided	17.1-	9.6-
Col. 24 - First seen in midair(P)	16.7+(I)	9.7+(I)
Col. 22 - Followed stroke to ground	[illegible].6-	3.2-
Col. 21 - Observer saw ball originate	7.2-	2.[illegible]-
Col. 71 - Had aftereffects(P)	7.1-	5.0-(I)
Col. 2 - Occurred before 1950	[illegible].1+	6.1+(I)
Col. 9 - Occurred over natural terrain	2.[illegible]-	4.[illegible]-
Col. 42 - Ball terminated within 50 ft of observer:		
Col. 26 - First seen within 10 ft of observer(P)	67.3+(I)	51.0+(I)
Col. 40 - Approached within 10 ft of observer(P)	31.1+(I)	18.8+(I)
Col. 27 - Diameter less than 15 in.	19.6+	10.3+
Col. 9 - Occurred over natural terrain	17.0-	7.2-
Col. 10 - Observer within building or vehicle	11.9+	3.4+
Col. 41 - Approached within 1 ft of solid	[illegible].0+	3.7+
Col. 48 - Passed through apertures, etc.	8.1+	4.[illegible]+(I)
Col. 14a - Unconnected with a storm	[illegible].7-(I)	3.2-(I)
Col. 5 - Occurred over flat terrain	4.0+	2.4+
Col. 53 - Final velocity of ball under 3 mph:		
Col. 43 - Maximum velocity under 10 mph(P)	17.9+	9.9+(I)
Col. 58 - Minimum velocity under 4 mph(P)	1[illegible].8+	6.9+
Col. 45 - Observer saw ball terminate(P)	[illegible].3+(I)	7.8+(I)
Col. 71 - Aftereffects were reported:		
Col. 43 - Ball ended quietly(P)	14.6-	13.7-
Col. 51 - Ball terminated in middle	[illegible].1-(I)	5.0-(I)
Col. 37 - Accompanied by odor	6.0+	7.1+(I)
Col. 22 - Followed stroke to ground	4.3+	3.6+(I)
Col. 36 - Accompanied by sound	4.2+	1.9+
Col. 58 - Minimum velocity of ball under 4 mph:		
Col. 43 - Maximum velocity under 10 mph(P)	27.[illegible]+(I)	24.6+(I)
Col. 53 - Final velocity under 3 mph(P)	1[illegible].8+	6.9+
Col. 52 - Motion not only horizontal	[illegible].5+	2.6+
Col. 21 - Observer saw ball originate	3.[illegible]+	3.3+
Col. 69 - Ball observed through glass or screens:		
Col. 10 - Observer within building or vehicle(P)	24.5+	29.0+(I)
Col. 5 - Occurred over flat terrain	6.9+	6.3+
Col. 2 - Occurred before 1950	[illegible]-	[illegible].0-
Col. 27 - Diameter under 15 in.	4.1-	[illegible].1-
Col. 14c - Occurred late in storm	3.7-(I)	3.6-(I)

[a] I denotes insufficient data.

[b] P denotes predictable correlation.

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