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Vapor Phase Electrochemistry 4: Cylindrical Air Plasmas

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ABSTRACT

The most puzzling of all atmospheric phenomena are probably UFOs (Unpredictable Flying Objects). Earth-lights are similar but they are smaller and far less familiar. An electrochemical model that explains all the characteristics of ball lightning now can explain most characteristics of UFO and earth-lights. Despite their very different appearances, all three phenomena owe their structural stability to exactly the same forces. The fact that UFOs usually appear to be largely metallic while lightning balls usually glow brightly is easily explained. However, one characteristic of UFOs seems never to have been reported for lightning balls. This is prolonged tracking of an aircraft while a kilometer or more away from it. It is shown here that assuming the chemistry to be the same in all three structures can fully explain (qualitatively) how the same forces hold several air plasmas together. The most familiar cylindrical plasmas are lightning bolts, but still little is understood about the earliest (invisible) stages of air breakdown which rapidly produce the so-called stepped leaders that then lead to conspicuous lightning strokes. It seems that long thin air plasmas, similar to the invisible early lightning precursors can explain the tracking of aircraft by UFOs. Similar invisible plasmas can also explain why roughly horizontal lightning discharges are so common. An additional requirement for the existence of long, horizontal air plasmas is probably near perfect charge neutrality over the whole length of the invisible cylindrical plasma. Modeling only the physical aspects of the processes (for mutual UFO interactions) could prove feasible and might help improve our understanding of all naturally contained air plasmas: spherical, spheroidal and cylindrical.

KEYWORDS

UFOs, earthlights, ball lightning, air plasmas, tracking, electrochemistry.

INTRODUCTION: NATURALLY CONTAINED AIR PLASMAS

Ball lightning is the simplest form of contained air plasma and about 10,000 accounts of its behavior had been reported to scientists by 2002 (Singer, 2002). These accounts go back many centuries and a good fraction of the sightings were witnessed by several individuals. Many people are unfamiliar with even the existence of ball lightning let alone all its strange properties. Taken together, its wide variety of puzzling characteristics have long been seen as anomalous in that, in combination, they appear to violate some well-established laws of physics.

Numerous models have been proposed that can explain *a* few ball lightning characteristics but no early model could explain them all. This situation changed significantly when the Russian physicist, Stakhanov (1979) published a model that was based on what he called his cluster hypothesis - the clusters being hydrated ions. This model could account for nearly all of the apparently anomalous characteristics of ball lightning and it was the first one that even attempted to do so. The model was improved and extended between 1994 and 2002 (Turner, 1994, 1996a, 1996b, 1997a, 1997b, 1998, 2001, 2002) by which time it was quite clear that ball lightning is a single phenomenon that violates no known law of physics. A much more detailed justification of this claim was provided recently (Turner, 2023).

It has also recently been shown that air plasmas can combine together in tight groups, each of which behaves precisely as if were a lightning ball (Turner, 2024). The extensive studies of earth-lights that were made over more than two decades in the Hessdalen valley of Norway (Teodorani, 2004) showed the apparent structural connection that exists between lightning balls and UFOs.

The earlier mentioned improvements to Stakhanov's ball lightning model were made possible because it was already clear, to a few chemists working in support of the electricity supply industry, (Gates et al., 1982; Turner, 1980, 1983, 1987, 1988, 1990; Wood et al., 1983) that no valid theory exists that applies to the chemistry of ions in a moist gas. The later improvements to Stakhanov's 1979 model were based on a simple acceptance of this fact and then finding a way to circumvent it (Turner, 2023, 2024). Recently, experimental evidence supporting key elements of the electrochemical model have been reported (Bartlett & Turner, 2025).

One of the longstanding beliefs of some physicists interested in ball lightning is that the so-called virial theorem excludes the possibility that naturally contained air plasmas can exist (Singer, 1971). The theorem has proved very useful in many fields of physics and engineering (Collins, 1978; Singer, 1971). However, it ignores the possible presence of chemically produced forces. The mere existence of flames (where the inflow of air holds the plasma of a flame together) might have made it clear (though it did not) that such arguments are irrelevant when chemically derived forces are present (Turner, 2024).

A convenient way of thinking about air plasmas is that they burn nitrogen instead of a hydrocarbon gas. The reason these plasmas are so rare is that the plasma surface needs to be refrigerated. This is because nitrogen "combustion" is only thermodynamically possible below a temperature of 15 °C (Turner, 1998). Physical and chemical conditions favoring the refrigeration process rarely happen to be optimal (Turner, 2024). The impurity content of the air, for example, has to be optimal as do the local relative humidity and electric fields. Our repeated failures to prepare these plasmas under laboratory conditions result from our ignorance as to what exactly these optimal conditions are.

Stakhanov (1979) based his model on well-established ball lightning accounts plus many new accounts supplied to him following his request for such reports in a popular Russian science magazine. In his 1979 book, he reviewed all the apparently anomalous characteristics of ball lightning and provided a largely electrochemical explanation for most of them. However, his model could not explain the most energetic plasma balls reported. Nor could it explain the origin of one essential ingredient of the model: a surface tension for the plasma ball.

He had estimated a range of reasonable magnitudes for the surface tension of the balls from such reported characteristics as bouncing and squeezing through holes much smaller than the balls themselves. The inability to explain this apparent surface tension was clearly the least satisfactory aspect of the model since it is essential in explaining both the recovery of a plasma ball from a distortion and how the hydrated ions of the plasma could be kept separate from the air that surrounds the ball.

By 1993 it had been realized, by a small number of chemists in, or supporting, the electric power industry that there are serious theoretical limitations in modeling ions in water anywhere near the fluid's critical point. This is at a temperature of 374 °C and a pressure of 221 bar (0.1 MPa or 221 times atmospheric pressure). Detailed descriptions of these difficulties are provided elsewhere (Turner, 2003). Related limitations make it impossible to quantify the properties of ions in moist air and so in all natural air plasmas (Turner, 2023). This fact was first pointed out much earlier (Chown, 1993).

The most concise way of clarifying these limitations is to note our current inability to quantify the consequences of electrostriction of water molecules in the huge electric fields near to any ion in a moist gas. It had early seemed likely that this problem and the limitations of Stakhanov's (1979) ball lightning model were related. Stakhanov based his model on measurements of the hydration thermodynamics of the ions that he thought would be present. In support of his model, he pointed out that ion clusters exist as stable entities in the ionosphere (Narcisi

& Bailey, 1965). The thermodynamic measurements had (of necessity) all been carried out at very low gas pressures. As a result, in none of the thermodynamic studies were any data obtainable for hydration numbers greater than seven.

It later proved possible (Turner, 1994) to obtain data for much more heavily hydrated ions by simply interpolating between the mass spectrometry data available and those for aqueous solutions containing the same ions. This approach was used following an earlier observation that the gas phase thermodynamic properties of ions seemed to be fully consistent with those available for aqueous solutions containing the same ions (Kebarle, 1974). This exercise led directly to the basic improved version (Turner, 1994) of Stakhanov's (1979) model for ball lightning.

Using this approach, most of the apparently anomalous characteristics of ball lightning were easily explained qualitatively. However, as had been demonstrated clearly by 1990 (Turner, 1980, 1983, 1988, 1990), very few properties can be known quantitatively. This is because of a range of connected knowledge gaps that result from our totally inadequate understanding of electrochemistry in a moist gas (Turner, 2023). Serious consequences of this problem had first been uncovered as a result of some industrial problems where a very compressible fluid (steam) was involved (Turner, 1987). Later it was realized that the same phenomena restrict what can be modeled (validly) in moist air (Turner, 1994).

By 1998, it was clear that ball lightning can extract chemical energy from the air (Turner, 1998) and it was eventually found that all the characteristics of the phenomenon are explicable - though only qualitatively (Turner, 2002, 2003). It can now also be seen that the structure of no other known form of air plasma, including variously shaped UFOs, is in any way anomalous (Turner, 2024). Still more recently, experimental support for the most important assumptions in the 1994 ball lightning model was reported (Bartlet & Turner, 2025). Fortunately, even in the absence of valid theories, all the qualitative characteristics of air plasmas can be explained.

OBSERVATIONS OF UFOS (UNPREDICTABLE FLYING OBJECTS) AND RELATED AREAS OF CONFUSION

The whole subject of UFOs is controversial. This is despite the large quantity of evidence supplied by aircraft pilots. They occasionally claim to have been tracked by metallic looking objects, sometimes at a very long range. In addition, frequent claims are made that these objects can move at speeds that no conventional aircraft could possibly match. In an early book on UFOs, Klass (1968) collected together a variety of evidence demonstrating that UFOs and ball lightning are both air plasmas and therefore, he claimed, he had explained UFOs. The only valid criticism of this conclusion is that any similarity between lightning balls and UFOs does not represent a complete solution to the problem since the former objects are themselves poorly understood. In fact, much earlier than this, Galli (1910) simply assumed that a single phenomenon exists, whatever its' shape. The shapes included cylinders, cones, prisms and plates.

In practice, the apparent violations of the laws of physics, with both ball lightning and UFOs have contributed significantly not only to confusion but also to the inhibition of research on both ball lightning and UFOs (e.g. Hynek, 1972, 2020; Sturrock, 1999; Turner, 2023, 2024). Excessive specialization has not helped either (Smirnov, 2000; Turner, 2001, 2002) and a variety of other societal problems has made matters worse (Turner, 2023).

It now seems clear that Klass's kind of logical, though purely qualitative, arguments can all be seen as realistic once it is acknowledged that vapor phase electrochemistry has never been brought to a state of development where quantifiable predictions are possible (see Turner, 2023). Evidence for the existence and characteristics of UFOs (e.g. Chester, 2007; Haines, 1994; Hynek, 1972, 2020; Kean, 2010; Smith, 1997; Vallee, 1965, 1993) is so strong that many serious investigators of UFOs find it necessary to invoke alien visitations or at least some unrecognized new mental phenomenon (Hynek, 2020). However, these claimed possibilities are not, in fact, the real problem. This is that we do not adequately understand the laws that govern almost any aspect of naturally contained air plasmas (Turner, 2023). Nor do most physicists realize the significance of the fact that a crucial part of physical chemistry is missing.

Possibly, the most unbelievable aspects of UFOs are accounts of sudden bursts of velocity (either speed or direction) that seem impossibly high. The speeds sometimes claimed would certainly be absurdly high if UFOs are solid. Since they are almost certainly balls of plasma, their velocities will be limited only by the speeds of molecules, which are extremely high (Turner, 2024). Also, air plasmas can be surrounded by thick mist (Haines, 1994) so that the strongly reflective surfaces of UFOs must really consist of fine water droplets - not a metal.

All the most seemingly impossible characteristics of the 473 UFO cases considered by Haines (1994) are explicable on the above basis. Rapid UFO motion, for example, would be produced as a reactive force that resembles the force of a jet engine but in the opposite direction. Air can enter a UFO most rapidly on any side of an individual plasma ball whose containing aerosols are smaller (or less numerous) locally than on the other sides of the ball (Turner, 1994, 1996a, 2001). Sudden changes in direction should not be surprising either since air contaminants unfavorable to surface stability will be invisible. Also, a group of insects swept into the UFO could have a huge effect. The few reliable records of UFO speeds, obtained from radar reflections (e.g. Hynek, 1972), seem consistent with these suggestions.

As mentioned earlier, the study of ball lightning and the study of UFOs are nominally similar in that almost all the direct evidence we have comes from witness testimony. This fact introduces concerns over the reliability of the evidence in both cases - but this is a minor problem. There is a far more important sociological effect: our longstanding need for specialization. One result has been that the influence of chemistry in air plasma stability has been almost totally ignored (Turner, 2002). Ball lightning has long been of interest to a minority of physicists, engineers and meteorologists and over 2,500 papers on the subject had been written by the end of the twentieth century (Stenhoff, 1999).

There appear to be several reasons why UFOs have been taken less seriously than ball lightning, some of which have been discussed recently (Turner, 2023, 2024). One problem with UFOs probably results from the very large sizes of some of the objects and their seemingly very advanced methods of propulsion and navigation. This hints at the possibility that either enemy aircraft or aliens are involved.

As a consequence, there is the very serious problem, first raised clearly by Hynek (1972), that military personnel, in many of the world's air forces, have been far more interested in the phenomenon than have most scientists. Despite this problem, and despite the large amounts of nonsense to be found in many books on UFOs, reputable scientists and laymen have written a few extremely informative books on the subject (e.g. Chester, 2007; Haines, 1994; Hynek, 1972; Kean, 2010; Smith, 1997; Vallee, 1965, 1993).

In contrast with the best studies of ball lightning, which tend to agree over almost all the facts (if not what they mean) the diverse characteristics available on UFOs makes it easy to understand why the coverage given to them has been so varied. Many of the claimed facts concerning the two phenomena are very similar but the basic problems, with both ball lightning and UFOs, tend to be viewed in quite different ways by people with different backgrounds. A common feature of the more rational books on UFOs is that, however hard they try, most authors cannot help revealing their beliefs. For these non-sceptics, this usually involves somewhat vaguely described suspicions of alien visitations.

The present approach does not need to invoke aliens. However, in order to explain all the reliable witness testimony, it is necessary to assume the presence of invisible plasmas connecting either multiple UFOs or one UFO and an aircraft. Many accounts have been reported of aircraft being tracked by groups of UFOs usually, it seems, with the UFOs at fixed distance apart (Haines, 1994). It is assumed here that the most instructive interactions are likely to be those between two UFOs - because the presence of a metallic aircraft cannot then complicate the arguments.

If long thin cylindrical plasmas connect two groupings of air plasma the connections would probably resemble the long thin plasmas first studied experimentally by Thomson (1893) and subsequently by many other physicists (Loeb, 1965). These studies (in well evacuated vessels) showed that faintly luminous glows can be transmitted at about a third of the speed of light but no-one seems to have found a way of using these findings in order to make useful quantitative predictions in lightning studies (Rakov & Uman, 2003). Even if such attempts had been made, they might well have been invalid because of the basic science that is missing (Turner, 2023).

THEORETICAL LIMITATIONS IN AIR PLASMA SCIENCE

We now need to address the nature of the most basic problem that restricts what can be validly calculated in a moist gas. In the 1980s, it gradually became clear to a few chemists working for the electric power industry in several countries, that the thermodynamic properties of ions, dissolved in the fluid phases near to water's critical point, are impossible to quantify realistically (Gates et al., 1982; Turner, 1980, 1983, 1987, 1988; Wood et al., 1983).

Later it was realized that this should be equally true of ions in moist air and this realization led to the improved version of Stakhanov's (1979) model for ball lightning (Turner, 1994). Seriously mistaken conclusions are inevitable if it is assumed that ion concentrations govern reaction rates when it is really ion activities that govern them (Glasstone et al., 1941). This means that there is no valid way of calculating either the kinetics or the thermodynamics of processes involving real ions (those at finite concentrations) in moist air (Turner, 2002, 2003, 2023).

In any kind of chemical change, including the mutual charge neutralization of ions, it is normally assumed that the rate of the process is controlled by the collision frequency of the ions. However, this is not strictly true for any chemical change. All rates of chemical processes are really controlled by the need to minimize the total free energy in the system. This means that it is really the thermodynamic activities of the reactants, not their concentrations, that control how fast any chemical change will proceed. Usually, for convenience, it is assumed that concentrations control reaction rates but it has long been known that this is no more than an approximation (Glasstone et al., 1941).

Unless the reactants are ions, the differences between concentrations and activities are usually small. However, if reactants are sufficiently hydrated ions in a gas, activities and concentrations can bear no known relation to each other (e.g. Turner, 1983, 1994). In fact, if hydration is sufficiently great, the differences can be so large that charge neutralization is thermodynamically impossible (Turner, 1990). Rate processes involving ions in moist air will continue to be impossible to quantify until the basic electrochemical problems are addressed (Turner, 2024). This will not be soon (Turner, 2023).

As implied earlier, the restriction on quantifying the properties of ions in real air is a result of the electrostriction of water molecules in the huge electric fields near the ions. It thus transpires that there is nothing at all anomalous about the properties of any air plasma. It is only our inability to quantify validly relevant thermodynamic and kinetic properties that makes the properties of lightning balls appear so mysterious.

When the author first realized that this was a possibility (Turner, 1994), he was unavoidably led to invoke the electrochemistry of nitrous acid to explain the structure of lightning balls. This exercise was only possible because the nitrite ion happens to be one of the few molecular anions whose thermodynamic properties are known. The most surprising and crucial property of nitrous acid in the gas phase is that it can exist in a metastable, fully ionized, form that will cool a plasma surface as it changes from its metastable to its stable form. The important role for nitric acid formation was only realized later (Turner, 1998). The formation of this acid explains how some lightning balls can survive long after the high electric fields produced in thunderstorm have vanished. The plasmas are, in fact, extracting chemical energy from the air (Turner, 1998). Experimental confirmations of crucial aspects of the relevant electrochemistry have recently been published (Bartlett & Turner, 2025).

Air plasmas other than ball lightning might also require strong electric fields to bring them to life, but this seems not to be the case. Of all the poorly understood processes concerning natural air plasma formation, one of the least well understood is ion formation in the air. It seems certain that by no means all air plasmas require large electric fields to ignite them; population inversions (of electron energy states) that result from appropriate electromagnetic fields can sometimes substitute for a spark (Handel & Leitner, 1994). They may always be important.

Another problem is that the most abundant initiator of ion formation in the atmosphere is ultra-violet radiation. Ionization in the air by UV is now known to be greatly facilitated by the presence of small quantities of certain sulfur compounds (Svensmark et al., 2007) or of appropriate organic compounds (Kirkby et al., 2016). Obviously, this could be true of other chemical compounds as well. Any compound can be ionized if a source of sufficient energy is available and the presence of specific contaminants in the air might well be crucial in the ignition of most air plasmas. However, for a plasma ball to possess a long life, nitrogen must surely supply the fuel. We concentrate here on the nitrogen chemistry that appears to be necessary in providing long lives to air plasmas. First, a few comments are needed on aerosols, since it is in these that the acids involved in containing air plasmas are formed.

Aerosols have been modeled since the end of the 19th century. The dependence of equilibrium vapor pressure, at an aerosol surface, on its radius was estimated very early by Kelvin (Thomson, 1872). Thomson (1888) later approximated the influence of a central electric charge. A commonly used relationship for combining these two influences was, later still, employed to estimate the equilibrium vapor pressure of water as a function of the number of water molecules that can be held in the field of a singly charged ion (Turner, 1998). On the basis of this relationship, it was found that a singly charged ion would probably need to be hydrated by at least 30 water molecules before the droplet containing it would be thermodynamically stable.

With each water molecule added after this, the stabilities of the aerosols continue to increase unless the ionic charge is neutralized. Of course, no real charged aerosol particle could continue adding water indefinitely without encountering other particles or molecules and some of these collisions might lead to rapid charge neutralization. We only possess a very rough picture of the very early stages of aerosol formation but we now know that charge neutralization, in some cases and in sufficiently large charged clusters, need not occur at all (Turner, 1998, 2023). We really know next to nothing about charged aerosols whose mole ratios of water to ion lie between about 5 or 6 and say 3.10^8 ! However, they do seem to be essential in stabilizing air plasmas (Turner, 1994).

THE EARLY STEPS LEADING TO LIGHTNING STROKES

In trying to understand more about invisible air plasmas, it is obvious that the earliest stages of air breakdown are important. Concerning these, Loeb (1965) has stressed the importance of Thomson's (1893) discovery of very fast moving, though very weak, pulses of light. Since then, vast numbers of studies related to lightning physics have been undertaken. These show how extremely complicated are the detailed processes involved in lightning initiation. The general picture established from the early studies of South African thunderstorms by Schonland (1932) has changed very little, but the detailed complications involved in all the stages of air breakdown have been greatly clarified since then (Dwyer et al., 2012; Rakov & Uman, 2003).

We now know that Loeb (1965) was correct that the early stages of air breakdown *can* involve extremely energetic pulses of radiation produced at the tips of so-called stepped leader strokes, where the electric fields are highest (Dwyer et al., 2012). There must surely be local chemical consequences of such UV pulses - and not only in the physical changes that can be measured remotely. In his very influential book on lightning, Uman (1969) commented on the generally unsuccessful attempts there have been to relate laboratory studies to field studies of natural lightning. On page 203 of this book, he made the following statement which seems to have influenced most later work (e.g. Rakov & Uman, 2003). It reads "The whole lamentable situation is well characterized by the various theories of the stepped leader.... In much of the lightning literature the words pilot leader and streamer have attained the status of explanations or theories. To name is not to explain."

The last statement is obviously true but this does not mean that all the laboratory studies that led the development of the ideas (such as those described by Loeb, 1965) are worthless or that they could never have led to more complete explanations of the earliest stages of electrical breakdown in the air *if* sufficient attention had been devoted to them. Some of the possible reasons that this kind of study has not been pursued in the past were pointed out fairly recently (Turner, 2023).

High energy photons produced in the earliest stages of air breakdown seem likely to be far more plentiful in sheet lightning than in forked lightning. This is partly because the energy density at the tip of a leader is so high compared with that in a conducting channel and partly because of the far larger volumes of air that seem to emit the radiation (as sheet lightning) during a thunderstorm. Sheet lightning can often be seen when a severe thunderstorm is viewed from a distance and sometimes only sheet lightning is visible for much of the time.

Experiments have shown that high energy UV radiation can produce aerosols containing both nitrous and nitric acid. The concentrations of both species are very low (Bartlett & Turner, 2025). The range of nitrate concentrations found in these experiments is actually quite close to (though somewhat larger than) the background levels of nitrate ions found in air that is unusually clean (Neubauer & Heumann, 1988). This similarity is unlikely to be a coincidence.

In the first paper in the present series (Turner, 2023), an attempt was made to identify most of the reasons why the science of vapor phase electrochemistry has been completely neglected over the last three decades. The main problem identified was that, as a result mainly of political decisions, it is no longer in anyone's interest to work on the various associated problems. The reasons seem to be very clear (e.g. Klein, 2014; Wolff, 2010).

Research that is unavoidably slow, expensive and very unlikely to bring short term financial benefit to any company, is no longer funded (Turner, 2023). The complete faith in the profit motive (which most clearly began to accelerate in the 1980s) has ensured that what small progress was once being made in the study of basic aqueous-phase electrochemistry has now ceased completely. Different factors have controlled studies in more obviously meteorological fields. For over two centuries, protecting people and property and saving money on expensive disaster relief following some catastrophe has been one of the most important driving forces for studies in meteorology. The areas of science that have most relevance in the present context all involve ions in moist air.

CHEMISTRY IN LIGHTNING INITIATION

The question most relevant to the matters discussed here is why so little attention has been given to the chemistry involved in thunderstorms. Apart from some very obvious practical difficulties, one answer seems to result from the need for individual scientists to make a living. This can only be achieved if the research on which they are engaged can be expected to make definable and significant progress within some clearly defined period of time. In the case of any really difficult study, such as that of lightning, there have to be clearly defined objectives and these can only be identified on the basis of what can be measured and what can be modeled. Of course, there is no guarantee that all the assumptions made in a model are valid - hence the accepted need for both modeling and measurement.

Lightning studies only began to make significant progress once new very high-speed photographic techniques had been developed and combined with electrical measurements on the ground (Schonland, 1932). As we have seen, subsequent progress has been considerable (Dwyer et al., 2012; Rakov & Uman, 2003; Uman, 1969). The most important advances have been made through extending the range of electromagnetic energies monitored during the studies. The study of artificially triggered lightning has also proved valuable. The fact that all the important processes occur remotely from the detectors and often behind thick clouds obviously makes the interpretation of the results obtained in real thunderstorms almost completely model dependent. Although some current models now seem to be generally accepted, not all are (Dwyer et al., 2012).

Regarding the chemical consequences of thunderstorms, we still know little more than that ozone and nitric acid are made somewhere inside thunderstorms (Goody, 1995) and that the radicals OH and HO_2, which could be their precursors, are also found there (Brune et al., 2021). How and where exactly the oxidation occurs can only be speculated. One very relevant fact that is now clear, is that nitric acid in the gas phase is thermodynamically stable only at temperatures below 15 °C (Turner, 1998). This means that the acid might form directly almost anywhere inside a thundercloud except in a visible lightning channel. More helpfully, we also know (Bartlett & Turner, 2025) that nitric acid forms easily in the presence of energetic UV in humid environments and it has long been suspected that pulses of this radiation are produced during the initial stages of air breakdown (Loeb, 1965).

The development of techniques for monitoring thunderstorms from space seem to confirm (if indirectly) current suspicions of where nitric acid is actually produced. These techniques have allowed what seem to be important conclusions to be drawn concerning the relationship between normal lightning and one of the less well-known forms of plasma that are produced well above thunderstorms. Close to the mesopause (beginning about 80km above Earth's surface) what are now termed elves can form. Their transient luminous properties are now reasonably well characterized. They are believed to be associated with gamma ray production during thunderstorms.

While the maximum current in the return stroke of normal lightning rarely exceeds 30 kA (Rakov & Uman, 2003) the peak current in the very brief intra-cloud discharges where gamma ray production is initiated can exceed 150 kA (Liu et al., 2017). The UV produced by these current pulses will inevitably create aerosols nearby - near the boundary between the conducting plasma and normal air. These aerosols will initially contain low levels of nitrous acid which are then rapidly oxidized to nitric acid (Bartlett & Turner, 2025). These processes presumably occur wherever nitric acid forms during thunderstorms. It is probable that most of the nitrates found in the air were originally formed, as aerosols, near where air breakdown first occurs and/or from the leader strokes which then go on to produce the return strokes that are so visually conspicuous.

Recent observations from the International Space Station identified the source of one gamma ray pulse that produced an elve. Several independent techniques provided a surprisingly precise estimate of the source of the gamma rays (Neubert et al., 2020): inside one small thundercloud. The cloud's area was about 20 km^2 and its maximum height above the ground was about 13 km. The position from which the gamma ray pulse came was about 1km below the cloud-top. The cloud was relatively small (Neubert et al., 2020) its area being less than a tenth that of a typical super-cell cloud. Its height means that it was well below the tropopause at its latitude (fairly near the equator) so that most of the nitric acid produced would have been eventually released into the troposphere and mixed with normal air.

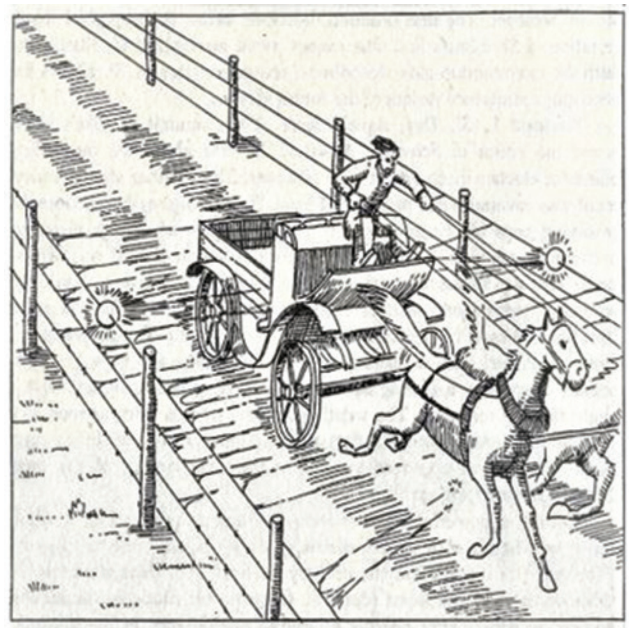
This finding is clearly consistent with the implication (made above) that the background nitrate content in the air is maintained by its formation at the surfaces of lightning strokes. Nitric acid could be produced in a variety of ways from the nitrogen oxides formed during thunderstorms or from pollutants in the air. Most polluting oxide sources are very local so that it is difficult to see why the nitric acid found in snowflakes in the Antarctic (Neubauer & Heumann, 1988) and in hailstones in the USA (Turner, 2023) should all have such similar concentrations of nitric acid if the acid is mainly formed from what are commonly called NOx pollutants. For these reasons, it now seems probable that the background level of nitric acid, in both rain and in ice (Mason, 1971), originates mainly where the initial electrical breakdown of the air occurs. The use of drones, capable of detecting very dilute nitric acid in aerosols, might make it possible to determine whether or not most of the acid is produced very near lightning discharges. Clearly, it would also be necessary to know where precisely the preliminary lightning discharges were located. Hence this kind of study is unlikely to produce decisive results very quickly.

Here we are only directly concerned with the processes that produce electromagnetic radiation at the tips of the structures that Loeb (1965) and others used to call pilot leaders. They may be identical to the lightning precursors that Schonland (1932) called α stepped leaders. However, studies of the kind just mentioned might be able to throw new light on the earliest stages of air breakdown. These processes inevitably involve such low energies that they cannot normally be identified in the presence of all the high energy processes that we know arise during thunderstorms.

THE TRACKING OF MOVING OBJECTS BY NATURALLY CONTAINED AIR PLASMAS

Although the tracking of aircraft by UFOs is well established, *closely* similar tracking of vehicles at ground level is rarely reported. Far more frequently, when a UFO approaches a motor vehicle, instead of tracking it over significant distances, the UFO will cause the cars' ignition system to fail, the car will stop and it cannot be re-started until the UFO has departed (Hynek, 1972; Vallee, 1965). However, there has been at least one published account of the tracking of a moving vehicle by plasmas at ground level. This account (Anonymous, 1896) was summarized by Corliss (1977). Figure 1 provides a clear picture of the event (taken from Corliss's book). In this event, a German farmer had been driving along a narrow road in May 1896 when he encountered two glowing spheres of St. Elmo's fire.

Such spheres can be considered to be small tethered lightning balls (Turner, 2023). The following is quoted from the original article by Corliss (1977) on page 31: "his attention was attracted by a bright light behind him. On looking around he saw fire balls about the size of a man's hand



Luminous electrified spheres race along fence wires to pace horse-and-carriage.

Figure 1. An Early Example of Vehicle Tracking by Air Plasmas. (Corliss, 1977).

traveling towards him along the wire on both sides. In a moment they were abreast of the carriage, and then traveled along with it *pari passu* (at an equal rate), while brush discharges and audible crackling, as from a large electrical machine, were observed to proceed from the fireballs towards, apparently, the iron parts of the carriage. Vibrations of the wires could be distinctly heard, and a torrent of sparks sprang over from the fences to the carriage and horses."

In this particular case, it might just be reasonable to assume that normal electrostatic forces, between the plasma balls and the carriage, were responsible for the observed tracking. However, the distance separating the wire and the carriage, if the sketch is to be believed, looks rather too large to be explained in this way. It is hardly possible that normal electrostatic forces could account for a somewhat similar experience that was reported to me nearly a century after this account by Jim Garrett. In 1993 Mr. Garrett had made contact after having read a brief, pre-publication, account of my 1994 ball lightning model in a popular science magazine (Zimmer, 1993).

In his letter he stated "I am fascinated with your explanation (of ball lightning) because for all these years I've wondered how a plasma could exist in free space without blowing itself apart". At the time of the observation, Mr. Garrett was studying electrical engineering but he was already somewhat experienced in the field. The observation was made during a severe Oklahoma thunderstorm in 1963. He first saw (to the side of his car) a bright white light as lightning struck what would have been the ground cable of a power line. He then saw an initially green ball of plasma grow rapidly from what he took to be the point of impact of the lightning bolt.

Once the (rapidly changed to white) ball, of basketball size, had formed, it accelerated to match precisely the car's speed, *of* about 55 miles (98 km) per hour. It then tracked the car (to the side but slightly in front of it) for about half a mile. The ball moved as if floating directly above the wire, possibly just touching it. The distance from the car to the wire was roughly 20m. This is similar to the closest distances occasionally reported for encounters between an aircraft and a UFO (Chester, 2007).

In this case, the separations were so large that normal electrical driving forces could not have been responsible. The tracking distance was later confirmed when the site was re-visited. It would be interesting to know for certain that, in the 1896 incident, the plasma balls really were centered on the wires and not floating above them - as in Mr. Garrett's observation. There were other unexplained details in the Oklahoma sighting, such as why the ball remained vertically above the wire with no apparent tendency for a displacement either towards or away from the car. This seems to have surprised Mr. Garrett almost as much as the tracking itself. The ball's vertical position was almost certainly the result of a dominant dc field. Such fields are thought to explain what used to be called the electrostatic guidance of lightning balls (Turner, 1998).

Because of the distance from Mr. Garratt's car, it is far more difficult to understand how a plasma ball could track the car's motion in a mainly horizontal plain. This it did, however, the ball accurately maintaining its height above the cable as the latter rose and sank between its wooden support posts. Apart from a fairly precise estimate of the separation in this case, the main differences between these observations and the numerous pilots' reports of UFOs tracking aircraft is that, in the latter cases, the plasmas tend to be brighter, very much larger, frequently much more distant and not obviously in communication with any (even poorly) grounded object.

Normal electrical forces could not possibly be the explanation for the numerous cases in which experienced pilots have reported tracking by UFOs that, on first observation, were estimated to be kilometers away from the aircraft being tracked. It has certainly seemed, and it has often been claimed, that only an intelligent being could be responsible for this characteristic of UFOs. However, it will be argued here that there is probably a perfectly feasible way in which an air plasma can track an aircraft or several UFO plasmas can move in formation. The latter is a fairly common occurrence in reports of UFO encounters (Haines, 1994).

The numerous reports of UFOs tracking aircraft are so strange that most physicists do not even try to explain them. Most disbelievers simply ignore them. However, there also exists a small collection of UFO reports that seem quite impossible to dismiss out of hand (Sturrock, 1999). Accepting the advice of the very experienced UFO investigator, Jacques Vallee, Sturrock assembled a few convincing pieces of evidence in his book.

In doing so, he may have provided a somewhat similar service to the study of UFOs to that provided a century and a half earlier by Arago (1855) to future studies of ball lightning. At the time, Arago could do little more than let it be known that the phenomenon was real and was worth serious study. He clearly hoped that there could be some future benefit in showing that the phenomena are real. His view was apparently not shared by most of his professional contemporaries (Singer, 1971).

A particularly convincing and very detailed account, of an encounter with a UFO in Ohio, was described in Sturrock's book, in a chapter written by Zeidman (1999). Most of the astonishing details of this encounter, during which a helicopter was elevated high into the air by the UFO, have been discussed recently (Turner, 2024). Here we only need to mention the fact that this UFO, like many others, tracked the aircraft for some time well before the close encounter. There was far less detail on the early part of the tracking than on what occurred later but one of the crew members, of which there were four, first noticed the distant object. It was positively claimed to be tracking the helicopter only when the objects were a few km apart.

This would have been within the range of those remote UFO encounters that are most commonly reported in peacetime. Much smaller UFOs, the so-called "foo fighters", were frequently reported during the second World War by military pilots (Chester, 2007). They usually seemed to consist of single balls of plasma closely resembling lightning balls. Similar small, single, plasma balls are occasionally reported now by passengers in commercial aircraft. They are normally seen fairly close to the wing tips of the aircraft. It may be significant that the small "foo fighter" plasmas seem to have been reported more commonly in war ravaged areas than in most places in peacetime. The air could have been very polluted in war zones and dusty air is thought to lead to the production of smaller plasma balls than does clean air (Turner, 2002).

RATE PROCESSES IN PHYSICS AND CHEMISTRY

If we are to seek a rational explanation for all of the well-established characteristics of UFOs, it is necessary to accept several of the points made in recent publications concerning naturally contained air plasmas (Turner, 2023, 2024). The first of these papers discusses some of the reasons why vapor phase electrochemistry has never been developed to a state where real gas phase mixtures containing ions can be treated quantitatively. The second paper contains an explanation for the structural aspects of UFOs as fairly large assemblies of smaller natural plasmas that resemble lightning balls. Due partly to the various limitations mentioned earlier, even less can be predicted concerning the well-established characteristics of UFOs than can be predicted for those of their component plasma balls. It seems that, even for lightning balls, only the range of sizes can be predicted (Turner, 2002).

The theoretical problems referred to earlier impose serious limitations on what is predictable of the properties of both ball lightning and UFOs. The limitations can be thought of as stemming from unavoidable differences in the way electrically charged systems are studied by particle physicists and by chemists. The exceptional power of physics comes from using centuries of work by (frequently amateur) mathematicians (Penrose, 2004).

Similar approaches in chemistry cannot be used because it is almost impossible to predict the energy levels for any molecule, ion or radical that is heavier than hydrogen. As a consequence of this fact, all the properties that control the interactions between chemical species need to be measured separately for each chemical species (atom, molecule, ion or radical) that is involved in any specific chemical reaction. There are 92 naturally occurring elements and the simply immense number of compounds they can form means that, in general, neither thermodynamic changes nor relevant rate processes can be usefully predicted.

We know very little about why exactly air plasmas are so rare. This is probably the main reason that no-one has ever succeeded in preparing a real, long lived, lightning ball - except by accident (Turner, 2024). Likely reasons for all our total failure to prepare artificial ball lightning intentionally are the following: (1) the local concentrations of contaminants in the air are not ideal, (2) the local electrical state is not appropriate, (3) the local air possesses a non-optimal temperature and/or temperature gradient and (4), most of the reactions that favor plasma formation would need to possess optimum rates (none of which we know).

It seems inevitable that optimizing all of these variables can only be achieved on the basis of many new experiments guided, as far as possible, by what we already know. A research program large enough to address all these needs is very unlikely to be supported in the present political climate (Turner, 2023). A combination of collecting unexplained observations already available, new observations of the phenomena and new experiments appears to be the only feasible approach. An example of what can be learned from this kind of study is the decades long program of observations of earth-lights that have been carried out in Norway in the Hessdalen valley (Teodorani, 2004).

Before attempting to draw new conclusions concerning long thin air plasmas, it seems appropriate to refer to an observation that was reported half a century ago in the Monthly Weather Review (Price & Carlstead, 1966). The authors were professional meteorologists at the U.S. Weather Bureau in Honolulu. They began their account with the following sentence: "Nature follows her own schedule, not ours; and her phenomena are to be seen only by chance, not by appointment."

The authors then go on to describe an extraordinary, almost unbelievable, experience of an elderly lady whose common sense, and accuracy of memory they were able to confirm for themselves shortly after the event. The observations (of horizontal lightning) were made while the lady was on a covered patio that overlooked her garden and whose area of view, in every direction, was strictly limited and precisely defined. Her question of the meteorologists was "... what made it die and in my garden?"

The basic facts are, that at the time of the occurrence, she was on the patio out-doors and happened to be looking towards a birdbath in her garden. This was situated 3.8 m from her viewing position as a lightning stroke passed very slowly in front of her between her position and that of the bird table. It hid the pedestal but not the actual birdbath on top and then suddenly extinguished itself without ever visibly changing its height above the ground. She stated that it appeared to be a brightly shining solid object that was "dazzling electric blue" and that it was traveling about 15 cm above the grass at a sufficiently slow speed for it to be in view for 3 or 4 seconds. The phenomenon observed has to be what is known as "rocket" or "slow" "lightning". These discharges travel far more slowly than do normal lightning bolts but much faster than the majority of lightning balls (Uman, 1969).

AIR BREAKDOWN AND LONG THIN AIR PLASMAS

Townsend (1915) was the first physicist to provide a mathematical description of electrical breakdown in the air. Much later, Loeb and Meek (1941) showed that real electrical breakdown is far more complicated than Townsend had assumed. Later still, Loeb (1965) stressed the importance of what he called "ionizing waves of potential gradient". These waves can form by charge neutralization at the tips of lightning stepped leaders.

As we have seen, the early studies of Thomson (1893), that were followed up by others, contributed to Loeb's concept of a pilot leader. As we have also seen, this concept was later dismissed by Uman (1969) as being of little value in understanding lightning. His conclusion, that such concepts as a pilot leader are of no help in developing quantitative models of lightning formation has proved correct, but this does not mean that the concept of a pilot leader is unlikely to be helpful in understanding long-distance interactions involving air plasmas.

A personal experience in 2017 seems relevant here. It occurred while my wife and I were traveling east on a particularly straight part of Interstate 90, between Gillette and Moorcroft, Wyoming, on the 24th of August. For half an hour or so on smaller roads in very stormy weather, we had watched an extremely dark sky ahead of us but eventually the whole sky was pitch black. From it extremely long and unusually straight and vertical lightning strokes to Earth were being generated.

They were obviously coming from a very limited number of locations. Shortly after we arrived at a long straight portion of the road, my wife pointed out that all the strokes were clearly coming from two well defined locations, one to our left and the other to our right. No other sources of lightning were visible and nor was any horizontal lightning. As we watched, it became increasingly obvious that the two lightning sources were never discharging at the same time, or even independently. Discharges were alternating between the source to our left and that to our right.

Depending on how bright the initial lightning discharges were, one, two or occasionally three discharges to our left were invariably followed by one, two or three discharges to our right, after which the process was repeated many times. During the whole time we were traveling on the straight road no discharges were seen from any other direction. It was as if electric charge was being selectively delivered to Earth from one of the positions and then similar quantities of charge would be delivered from the other position. Subsequent enquiries from the National Weather Service in Rapid City, South Dakota, confirmed that an isolated pair of lightning discharging areas had been recorded and that their positions were consistent with our observations. The separation of these two positions, over the duration of the storm, covered a range of about 1.6 to 2.1 km. Matt Bunkers from this weather station kindly provided these details.

Clearly, it is not easy for anyone to believe that a pair of well separated clouds can behave like this. Nor is it easy to accept that a large compact group of plasma balls is capable of being attracted to a helicopter as it was in the case described by Zeidman (1999). Numerous accounts of aircraft tracking by UFOs, as in this case, are equally difficult to believe (unless aliens are involved). When such apparent anomalies are reported, it is hardly surprising that some individuals, who have not themselves experienced such events, should be so happy to bury the evidence. This appears to have been the policy of the US Air Force for many decades (Hynek, 1972, 2020). But the evidence does exist in plenty and, once this has been accepted, some sort of natural explanation should surely be sought.

Evidence on these matters is particularly likely to be taken seriously by someone who has previously been forced to learn that valid quantitative theories for ion interactions in moist gases are lacking (Turner, 2023). Although the structures and visible characteristics of UFOs now have a perfectly rational explanation (Turner, 2024), the way a small group of UFOs track aircraft requires one, and only one, new assumption of any importance. Attention will now concentrate on this matter.

UFOs and lightning balls are both rare phenomena and it seems likely that, when both phenomena occur, the local impurity content of the air and its local electrical environment determine whether or not they are formed (Turner, 2024). We shall assume that, whatever these conditions may be, they need to be satisfied before any long, invisible (and probably thin) cylindrical air plasmas can form.

Long ago, Thomson (1893) discovered that feeble pulses of light can be produced inside 15 m long, evacuated glass tubes fitted with electrodes at each end. Much later, these and several subsequent follow up experiments were discussed by Loeb (1965). Very thorough evacuation of the tubes was apparently needed if reproducible results were to be obtained. The only requirement for the pulses to form was that one of the electrodes be energized by an electric pulse of sufficient magnitude. Under these conditions, the pulses would travel at about a third of the speed of light and they could be produced at will.

Loeb attributed these pulses of light to what he called ionizing waves of potential gradient. He raised the possibility that phenomena like this might always play a part in the very earliest stages of electrical breakdown in the air. However, his attempts to quantify what Thomson and others had found were, as noted earlier, soon found to be of little value in practical lightning research. Nevertheless, all the experiments discussed by Loeb, and his interpretation of them, still seem important. One obvious reason for ignoring the findings in real air is the very low pressures needed to obtain reproducible results.

At the very low gas pressures studied, any *sample of air* would essentially contain only nitrogen, oxygen and water vapor. As noted earlier, it seems that many impurities in the air can either promote or inhibit the essential processes that occur at an air plasma interface. Any sample of real air (at or near atmospheric pressure) will contain numerous gases in addition to nitrogen and oxygen. Water would have been unavoidably present in all the evacuated tube experiments because thorough baking of the glass tubes is very unlikely to have been attempted.

The long lengths of the tube that were used would have been almost impossible to bake and there is no reason to think that such a process was thought necessary. Multiple layers of water are always present on any glass surface that has not been thoroughly baked, so that the evacuated glass tubes used would be expected to have contained nothing detectable except for traces of nitrogen, oxygen and water vapor.

It seems worth considering the possibility that, in the complete absence of undesirable impurities (as in this case), feeble pulses of electromagnetic radiation could be observable even at atmospheric pressure if there were no impurities present. In what follows it will be assumed that, in real air on very rare occasions, undesirable and beneficial air contaminants can effectively cancel each other's influence so that pulses of electromagnetic radiation can pass along some cylindrical volume of air at atmospheric pressure. In other words, under these rare conditions, plasmas will occasionally form in the air, as some kind of temporary analogue of a coaxial cable.

These hypothetical objects will be referred to in what follows as "plasma cables". Short versions of them may well be crucial in the very earliest stages of lightning formation in which case they can possibly be considered to be precursors of what Schonland (1932) called α stepped leaders. Although these "cables" are no more than analogues of real cables they will still be referred to here as cables. Since they can only carry very small currents, they are unlikely to be visible in any thunderstorm.

The bright return strokes observed during thunderstorms are believed to be near perfect cylinders but the invisible "pre-leader" objects to be considered shortly might well be far less perfect than this. Local differences in air contamination would certainly be expected to cause departures from perfect cylindrical symmetry if not preventing the plasma cables from ever forming in the first place. If any did form briefly, so much irreversible damage would normally be done to the cable, shortly after its formation, that any incipient plasma cable would cease to exist.

Air breakdown has long been known to be produced in several stages (Schonland, 1932), the earliest stages being by far the least well understood. This is hardly surprising since the resulting electrical currents will be so small that they would be undetectable in the presence of the far more powerful radiation being produced in an active thunderstorm. Clearly, under the conditions discussed by Loeb, impurities that might influence chemical processes were all absent. We shall assume that, in appropriately contaminated moist air, Loeb's "ionizing waves of potential gradient" might still be transmitted, even at atmospheric pressure, over considerable distances. Of course, this would only be possible if all the air contaminants, over the whole length of the cable, happened to be present at relative concentrations that are near ideal.

The possibility clearly exists that rare combinations of contaminants in the air at atmospheric pressure, when combined with appropriate electrical conditions, would always cause favorable electrochemical processes to be established. However, an obvious difficulty in testing this possibility is that igniting the plasmas might require some other phenomenon, such as a population inversion to be present (Handel & Leitner, 1994; Turner, 2023). These phenomena might also be requirements for a long life - as could be optimal potentials and potential gradients.

The only certain requirement seems to be that optimal blends of chemicals are required for an air plasma to have a long life at atmospheric pressures. For all these reasons, it seems very unlikely that the models discussed so far could, on any realistic timescale, be subjected to the kind of falsification tests that Popper (1959) and many later scientists have argued are needed before they could be considered any real part of science. Qualitative arguments, however, could still provide instructive clues for use in future studies.

Electrical conduction in a gas is quite unlike that in an aqueous solution. In a liquid, anions and cations move at comparable speeds in the same region of the liquid. They yield transport numbers (the fraction of a current carried by ions of either charge) that usually lie between 0.3 and 0.7. The situation in a tube of moist slightly conducting air could hardly be more different. The electrons will flow in the center, held together by self-induced magnetic forces known as Bennet pinching (see e.g. Alfvén, 1981) while cations can only conduct current very slowly near the cylindrical surface of a plasma cable.

In any conducting cylinder of gas, some charge neutralization will presumably occur close to the electron path and this will heat the center of the cylinder where virtually all of the current is flowing. There need not be much electron scattering because of Bennet pinching. Thus, even a weak electron current could be strongly confined to the center of this hypothesized cable.

It might be possible to check these ideas by modeling - but only if no attempt were to be made explicitly to include chemical reaction rates. There is no chance that such rates could be employed validly (Turner, 2023). In practice, because of ion hydration on the outer surface of the conducting column the fraction of the current carried by cations will be negligible. This is almost the only certain fact. An obvious doubt is whether sufficient information is currently available to learn much more.

We now consider one of these hypothetical cylindrical tubes of slightly conducting air that connects two distant UFOs - or one UFO and an aircraft. It is assumed that the same processes are responsible for the apparent communication between the two sites of lightning initiation that were observed in Wyoming and was described at the beginning of this section. If a current can flow inside a cylinder that provides such communication, it is likely that alternating currents at a wide range of frequency could be present inside the plasma cable.

Clearly the processes being described are very complicated and, partly because of the basic science that is missing (Turner, 2023) there is little hope of reliably quantifying the relevant chemical arguments. However, the explanation for communication between a UFO and an airplane is considerably more plausible than is piloting of the UFO or UFOs by aliens. An important point is that (as with lightning balls) mechanical stability can be achieved only when the processes stabilizing the surface of the plasma have been optimized. This fact can easily explain why both spheroidal collections of air plasmas (such as UFOs) and any invisible connections between them are such rare phenomena.

A comparison of the required conditions for igniting air plasmas of different shapes can usefully be made here. Among thousands of observations of lightning balls, there are remarkably few where multiple balls are formed. The situation with UFOs is very different. Here it is quite common for multiple UFOs, at fixed distances apart, to be observed tracking an airplane. One of the few cases where multiple lightning balls have been reported occurred in 1876. In this case, the observation was of "numerous globes of light, the size of billiard balls, which were moving independently and vertically up and down, sometimes within a few inches of the observers, but always eluding their grasps" (Corliss, 1977, pp 35-36).

The latter observation simply confirms the electrochemical model for ball lightning which predicts that ball lightning is positively charged on the outside - with a negatively charged plasma inside it (Turner, 1994). Were it not for air inflow to each plasma ball inside a UFO, UFOs would not exist - because of electrostatic repulsion. From the very different ways in which the two types of air plasma behave it would seem that multiple UFOs are probably all (or nearly all) formed during cosmic ray showers. For this to be the case, the time required for plasma ignition must, therefore, be shorter than that required for cation hydration and stabilization.

COMMUNICATION THROUGH APPROXIMATELY CYLINDRICAL AIR PLASMAS

Once it is accepted that these rare structures are probably real, it is worth giving them a little further consideration. Having once established an electrical connection between two remote plasmas, a direct current or an alternating current can pass between them down the center of the cable. If this occurs, a long narrow plasma that acts like a high frequency transmitting co-axial cable would have been set up because the air plasma chemistry on the plasma surface is expected to be exactly the same in a cylindrical plasma as in a spherical one.

The electrons would move very fast near the center of the core with the outer conductor consisting of a chemically active and permeable sheath. The different forces involved presumably can, occasionally, ensure a fairly straight path between the interacting objects using some of the same forces as those that stabilize a lightning ball. Obviously, any sufficiently large chemical or electrical interferences with the outer conductor could easily destroy such a plasma cable.

In a thunderstorm, after a number of well described preliminary steps (e.g. Uman, 1969), a bright lightning stroke can be seen. If such a bolt finally strikes the ground, the plasma will have become far hotter than the first visible leader stokes: the so-called α stepped leaders (Schonland, 1932). Final strokes usually have diameters of a few cm (Uman, 1969). Presumably, very bright horizontal lightning bolts have similar diameters, but the earliest pilot leader strokes will surely have been very much thinner.

Now to consider these thin, invisible, columns of slightly conducting air. Sometimes and somehow, in several fairly well characterized steps, electrons cause extensive electrical breakdown and force their way through the air. The motion will be driven by a potential gradient that can vary rapidly (or hardly at all) in unspecifiable places along the cable and at different times.

Interest here is with the kind of long thin conducting plasma that is invisible and which can sometimes become an α stepped leader. It will be assumed that a current can flow inside these invisible cylinders and that the initially needed current has resulted partly from Loeb's ionizing waves of potential gradient (Loeb, 1965) and partly from Townsend multiplication. Shortly after this, a long narrow plasma would have been set up that acts as if it were a high frequency transmitting co-axial cable with electrons moving very fast in the core and cations becoming hydrated and moving very slowly on the outside. It is necessary to assume that the different electrochemical forces involved on the outside of the cable can occasionally ensure a fairly straight path between two interacting objects.

Obviously, air (with its contaminants) is free to enter the outer "surface" of this, not always straight, plasma cable. This fact could certainly ensure very short lives for most incipient cables but a few would probably have favorable electrochemical processes occurring over their entire length. Long straight, perfectly cylindrical, plasmas are probably rarely present in real air but the idealized system could represent a reasonable approximation to reality - except for the obvious fact that impurities might cause kinks in the cable or end its life. These complications will be ignored.

The central region of a plasma cable will clearly be the hottest part and refrigeration is absolutely necessary on its outer surface - if the plasma cable is to be really stable. Clearly any air contaminant that destroys the refrigeration processes on the plasma surface could easily lead to a collapse of the plasma surface (Turner, 2024). There seems no reason why processes that are chemically exactly like those in a lightning ball, should not be needed to stabilize the outer surface of the cable.

For no part of the proposed mechanisms can reliable quantitative input data be even guessed so that obviously no detailed suggestion could be either proved or disproved. However, once it is admitted that there might be natural equivalents of coaxial cables, electrostatic interactions over long distances are qualitatively understandable and forces between the objects might be explicable. If this is the case, there would obviously be no need to invoke alien pilots or groups of alien pilots to explain any UFO tracking observation. The above qualitative arguments at least seem reasonable.

Apart from our longstanding ignorance in the field of vapor phase electrochemistry, there is another matter that is usually ignored. It relates to the fact that, in all electrical studies on Earth, the generally agreed state of zero potential is that of the Earth's surface, the Earth being approximated as a perfect conductor of electricity. It had been early realized by Kelvin (Thomson, 1860) that, since we know nothing about the electric charge distribution in the Universe, this zero state of potential is simply a matter of convenience and no true zero of potential can be known. However, this restriction would not apply if there were to be some way by which perfect charge neutrality could be ensured and identified.

The huge number of molecules involved in any measurable property of a gas normally ensures that an exact equality of charge is neither measurable nor achievable. Guggenheim (1967) used this argument concerning electrolyte solutions in liquids. However, the processes being maintained in an invisible plasma cable in the air might well require a very precise balancing of charge either inside or very near the plasma cable. If so, its height above the Earth could be a crucial constraint on its stability.

The electrochemical processes that stabilize the surface of any air plasma might well require an absolute balancing of charge somewhere within or very close to the cable. It seems quite possible that this requirement, for local charge balancing, is why nearly all reported interactions between UFOs and aircraft are so close to horizontal. The reported heights of UFO tracking can vary from about 18 km down to 20 m (Haines, 1994) but UFO tracking is hardly ever (if ever) seen to deviate far from horizontal.

Differing (horizontal) heights observed in UFO tracking seems reasonable when the large-scale electric currents flowing in the atmosphere are considered. The fact that UFO tracking of aircraft does not seem to be observed during thunderstorms confirms these arguments since current flow in the air is only strongly concentrated near thunderstorms, the current flow from the Earth being concentrated above these storms while that flowing in the opposite direction passes through vastly larger volumes of fair weather air. UFO tracking always seems to be reported in fair weather.

In a normal aqueous phase solution, the (arbitrary) standard by which redox potentials are compared is zero for the reduction of a proton to hydrogen gas. It is only at 25^0 C that many redox potentials are known. According to the compilation of Lide (2003), they range between - 3.09 and + 2.65V for all known redox reactions between nitrogen, oxygen and water. In the absence of any evidence to the contrary, we can only assume that the spread of redox potentials in the gas phase (if it could be measured) would not be orders of magnitude larger than it is in water.

The electrical potential of the ionosphere with respect to that of the Earth varies between 150 and 600 kV and the average height of the ionosphere is about 300 km. (Krider & Roble, 1986). These values are model dependent, though they are generally considered reasonable. A few measurements of atmospheric potentials, based on electric field measurements in and just above thunderstorms, are also available (Marshall & Stolzenburg, 2001). For heights well above cloud level the voltage range is -24 to +70MV. These studies were made near to 9 storms. The measurements were made up to about 9 km height. In comparison with these potentials, a spread of 6V or so is minuscule and the range of UFO tracking heights therefore seems reasonable.

In other words, chemistry does not significantly influence the heights at which UFOs track aircraft and it is reasonable to assume that the height representing an absolute potential of zero is close to that at which both UFO communication and horizontal lightning are observed. As we have seen, UFO tracking has been observed at heights between 20 m and 18 km (Haines, 1994). The wide range of potentials in the air seems consistent with the implied claim, made earlier, that this tracking can only occur at a height where the absolute atmospheric electrical potential is very close to zero, at which potential the concentrations of positive and negative charges are exactly equal.

These arguments obviously apply only to long cylindrical plasmas, not to spheroidal ones. While UFO tracking always seems to be near horizontal, individual lightning balls can be stable all the way between cloud height and ground level. It is possible that these differences might, in future, make it possible to learn more about all air plasmas: at present it only confirms that the local electrical state of the atmosphere is one of the parameters that allow naturally contained air plasmas to form and survive.

FORCES INVOLVING PAIRS OF REMOTE UFOS

The chemical and electrochemical processes that occur on the outer surfaces of conducting plasma cables and stabilize their structures are believed to be identical to those that stabilize the surfaces of lightning balls. (Turner, 2024). Reports of aircraft tracking by UFOs (Haines, 1994; Turner, 2024) show that these phenomena usually last far longer than do most lightning balls. This implies that the Bennet pinching, which is only possible in a cylindrical air plasma, assists greatly in the purely electrochemical effects that occur on the surfaces of all air plasmas. Bennet pinching is known to be extremely important in the interstellar medium (e.g. Alfvén, 1981) and it seems to be similarly important in cylindrical air plasmas on Earth.

In a group of UFOs tracking an aircraft, the UFO-UFO connections are not always horizontal. However, the absolute space charge is unlikely to be far from zero in fair weather over the observed distances between UFOs that are tracking an aircraft. The fact that tight groups of interacting plasma balls seem to lose one member of the group very rarely, if at all (Haines, 1994), is probably because groups of UFOs emit large quantities of UV, which then support the overall stability of the assembly.

When considering plasma cables, we are concerned only with processes that resemble the undetectable ones that precede the first stepped leader stroke of a lightning discharge. These would be the α stepped leaders of Schonland (1932). Although the range of heights over which UFO *tracking* occurs can now be understood, the forces between the communicating objects remain to be explained. For simplicity, we will consider only the case of two well separated, but identical, interacting plasma balls (one from each UFO). In this case the two ends the cable will be electrochemically identical unless there is some change in the energy content (brightness) of one of the interacting balls. The forces between two objects when an aircraft is at one end of the cable may not differ greatly from those between two interacting UFOs.

An invisible air cable obviously differs greatly from a real co-axial cable. To the absence of metallic conductors must be added the fact that the outer surface of the cables is electrochemically active and so potentially unstable. The conductances of both the inner and outer conductors in the air will clearly be far lower than in a real coaxial cable. A circuit equivalent to this plasma cable could be defined in principle. Presumably, it would somewhat resemble that of a coaxial cable terminated by a resistor that is much higher than the value defined by its effective dimensions. In other words, the real impedance of the invisible plasma cable would differ greatly from one terminated by its characteristic impedance. For this reason, if a pulse of current passes down the cable, there would be repeated pulses up and down it (from reflections at the ends) just as in the case of a real coaxial cable (see e.g. Schelkunoff, 1963).

A cable between two remote UFOs will presumably be connected through a single plasma ball at each end of the cable. We know from the findings at Hessdalen (Teodorani, 2004), that the plasmas making up an earth-light can be subject to considerable changes in energy (i.e. brightness). The studies also imply that the occasional inflow of contaminants, such as pollen grains or the occasional insect, or a sudden input of electromagnetic energy, can cause such changes. In an interacting pair of remote UFOs, a sudden change in the power of one of the UFOs would start a pulse of current between the two UFOs - thus establishing communication between them.

Obviously, communication between two UFOs cannot, alone, explain how they produce a force that holds them at fixed relative positions. We consider two UFOs at some unspecified but considerable distance apart with a series of current pulses flowing up and down the plasma cable between them. When the electrons flow into one of the balls, a reduction in charge on the outer surface of the plasma ball will result. A signal will then return down the cable and a similar neutralization of the surface of the plasma ball at that end of the cable will occur. These pulses will then proceed up and down the plasma cable because there is such a large mismatch between the actual and characteristic impedances of the plasma cable.

The effective masses of the central "wire" of the cable and of its "surface" will be very different because of the huge difference in the masses of electrons and hydrated ions. If mechanical forces along the length of the cable are to result from pulses of electricity they will, as a consequence of Newton's third law, only be important for the plasma cable's sheath, since electrons are far lighter than hydrated ions. Relative movements between two UFOs or a UFO and an aircraft could arise as a consequence of chemical changes somewhere along the length of the cable.

Haines' approach to UFO study (Haines, 1994) was to provide brief summaries of hundreds of convincing UFO reports. On the basis of the reports available to him, it seems that, when a group of UFOs track an aircraft, the individual UFOs usually seem to remain at fixed relative positions. UFOs sometimes do slowly approach an aircraft although they never seem actually to collide with it. It seems that, at close range, the forces of electrostatic repulsion prevent collisions between UFOs and aircraft.

CONCLUSIONS

Air inflows control the structures of UFOs in exactly the same way they do with lightning balls. The presence of cylindrical air plasmas between a UFO and an aircraft or between neighboring UFOs can be explained similarly. However, additional forces (Bennet pinching) will also be present in a linear plasma and this phenomenon can provide additional stabilization to a cylindrical plasma. These facts are only likely to be accepted once it is understood that electrochemical forces stabilize all air plasmas and that no valid theories for ion-ion interactions in real air are currently available.

It now seems clear that our ignorance concerning cylindrical air plasmas is at least as great as it is for spherical plasmas. In both cases the only real anomalies are that less is understood about them than with most other natural phenomena. Precisely the same ignorance seems to apply to the invisible phenomena that precede all visible lightning leaders: the pilot or α stepped leaders. We currently have no idea why the earliest stepped leaders are limited to lengths of about 50 m while interactions involving UFOs are sometimes reported for distances of several km. Neither can we predict the closest possible distance between an aircraft and a UFO. One obvious requirement for a stable plasma cable is that electrons in long cylindrical plasmas are not significantly accelerated at right angles to the axis of plasma. It might be instructive to investigate the possibility that crude models based on the earlier suggestions here could predict the length of early stepped leaders or at least the relative lengths of lightning leader strokes and typical aircraft tracking distances.

All the reliably reported characteristics of air plasmas can be explained once two facts are accepted. The first is that all these phenomena (including those where the lights are completely obscured by thick mist) are held together by electrochemical forces identical to those that hold lightning balls together. As with gas flames, it is the inflow of air, driven by chemical reactions, that holds an air plasma together. The second important fact is that no valid theory for the interactions between ions in a moist gas exists. Clearly, most of the arguments presented here lack quantitative support. However, they do provide a far more reasonable explanation for the UFO tracking of aircraft than their tracking by alien pilots in craft that possess seemingly impossible flight characteristics.

A possibility, not discussed here, is that, since the storms which produce tornadoes probably always contain spheroidal air plasmas, cylindrical connections between these plasmas might possibly play a part in explaining the formation of hurricanes from individual tropical storms over the ocean.

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CONFLICTS OF INTEREST

There are no conflicts of interest to disclose.

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