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ELECTRIC DISCHARGE AS THE SOURCE OF SOLAR RADIANT ENERGY*

RALPH E. JUERGENS

"[The] phenomena of electrical discharge are exceedingly important, and when they are better understood they will probably throw great light on the nature of electricity as well as on the nature of gases and of the medium pervading space." – James Clerk Maxwell(1)

Compiler's Comment (ERM):

In August 1972 Ralph Juergens introduced the concept of the electrically powered Sun.(1a) He was inspired by Immanuel Velikovsky's contention that electromagnetic forces played a crucial role in sculpting the surfaces and shaping the orbits of the bodies of the solar system;(1b) by Melvin Cook's attempts to unify the electromagnetic and gravitational fields;(1c) and by the voluminous literature of Charles Bruce intimating that the phenomena observed in stellar atmospheres could be described adequately by an electrical discharge model.(1d)

Juergens, however, went farther than all of his preceptors in electrifying both the cosmic bodies and their interactions. He perceived the astronomical bodies as inherently charged objects immersed in a universe which could be described as an electrified fabric.(1e) The charges appearing locally on cosmic bodies, he posited, arose from the separation of positive ions and electrons on a galactic scale.(1f) Later, he discussed both the problems arising if the solar interior is truly the source of stellar energy (1g) and the nature of the phenomena observed as the solar photosphere.(1h) The two papers cited in notes (1g) and (1h) were the last he published about the electrical Sun before his untimely death in November of 1979.

In the first of his papers, Juergens related the Sun's ability to modulate the incoming flux of cosmic rays (which are protons impinging

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upon the solar system from all directions at relativistic velocities) to the Sun's driving potential, its cathode drop.[1i] He estimated that a value in excess of 10 billion volts would suffice. From the flux of solar wind protons observed at the Earth's orbit, he calculated that a 10^{15} ampere solar wind current was flowing because of the solar discharge.[1j] The solar luminosity of 3.9×10^{26} watts seemingly requires a discharge current which exceeds that of Juergens' estimate by forty fold, but since both the cathode drop and the discharge current values he chose were minima, the power shortage is not likely serious, as either or both values can be adjusted to erase the deficit without affecting the credibility of his arguments.

Then, Juergens showed that the solar photosphere can be compared to a "tufted anode glow" in an electric discharge tube.[1k] The tuft forms because the body of the Sun, immersed in the interplanetary plasma, which at its inner boundary is the weakly luminous outer solar region called the corona, cannot maintain an electrical discharge into the surrounding electrified galactic space. Juergens noted that the problem could arise from any one or more of the following conditions: (*1*) the solar body forms too small a surface to conduct the current required for the discharge, (*2*) the surrounding plasma is too "cool",[1l] and/or (*3*) the cathode drop is too large. The "anode tuft" detached from, and now lying above, the "surface" of the solar body increases the effective surface area over which the Sun can collect electrons. Within the "tuft", volatile material – vapourized from the Sun – increases the gas density and contributes large numbers of extra electrons because, now, many of the frequent collisions between the gas atoms result in ionization.

A highly luminous arc discharge thus forms between the Sun and its environment; it stabilizes the electrical flow between the Sun and surrounding galactic space. This secondary discharge – the granular solar photosphere – provides the needed additional electron flow towards the Sun, thereby allowing it to launch an appropriate ion current from the Sun to the galaxy.

Here, in the first of a series of posthumously published papers, is Ralph Juergens' investigation of the cathodeless discharge which impinges upon the Sun from galactic space. This paper – like others to follow – was incomplete when Ralph Juergens died, yet it poses several crucial questions. It is published now, not as a final word on the subject, but as a springboard to launch the interested investigator towards a better insight into the phenomenon of electric discharge between the Sun and galactic space, and also to recognize Ralph Juergens as a pioneer in the study of electric stars.

ELECTRIC STRESS IN STELLAR ENVIRONMENTS

Deliberate avoidance of the subject of ordinary electricity by astrophysicists may not actually reflect, as Velikovsky once charged, "a reluctance . . . in danger of becoming a dogma, called upon to protect existing teachings in celestial mechanics."(2) However, the posture that justifies such behavior surely is compromised by the observation that cosmic space, like the stars themselves, is permeated with matter of excellent electrical conductivity.

Notwithstanding, scientists tacitly continue to assume that the physical isolation of the Sun, or any other star lacking a close companion, is total. *If it can be assumed that the Sun's properties (such as luminosity, temperature, or stability) arise from its essence (chemical composition, mass, and size), mathematical models describing stellar processes involve simple correlations between the physical description of the Sun (or star) and its observed output.*(2a) *But if the causal parameters are presumed to be determined by the conditions in the space surrounding the solar system, and not from the Sun's essence, then mathematical investigations must include an appropriate mapping of the Sun's (or other star's) environment – a presently unexplored field – before any analysis of the Sun's (or other star's) behavior is possible.*

In the past, others have considered the possibility that stars such as the Sun may be powered from the outside, with some "subtle radiation" traversing space providing the power. Such a notion has been greeted with disdain by scientists who prefer an invisible energy source, buried within the solar interior, to an invisible source that surrounds the solar system and is connected "subtly" to the Sun.

As to subtlety, any "radiation" invisible to an Earth-bound observer would satisfy this specification.(3)

Electricity – or more appropriately, *electric discharge,* since we are concerned with a phenomenon occurring in a gaseous medium – seems to offer precisely the qualities of "subtle radiation" that we are looking for. Electric discharge is a known and observable phenomenon, yet we might live immersed in a cosmic discharge and know nothing of its existence.

Without understanding its ultimate nature any more than we understand the nature of the gravitational field, we know that the electric field is potentially one of the greatest storehouses of energy in the universe.

Electric discharge offers phenomena so numerous and so diverse that we have little trouble finding analogs for every observable feature of the Sun. Moreover, we need not liken one aspect of the Sun to an arbitrarily chosen discharge phenomenon and then liken another feature of the Sun to another arbitrarily chosen discharge feature; a system of logically and physically related discharge phenomena can be shown to correspond, feature for feature, with the known properties of the solar atmosphere.

This correspondence is so striking that we can only presume that, in all likelihood, it has been noticed before – and repeatedly so. Why, then, has astrophysics avoided calling attention to it?

Electric discharge, for all its attractiveness as a source of cosmic energy, and notwithstanding the spectacular effects it produces in the Earth's atmosphere, requires the establishment and maintenance of electric fields and potentials that are quite inadmissible in the received view of the cosmos, in which isolated stars exist as self-sufficient generators of the energy they radiate.

Hannes Alfvén has been a pioneer in seeking understanding of the cosmic roles of electricity and magnetism. Yet, by accepting the prevailing notions that the universe is inherently neutral and that the stars are powered internally, Alfvén has effectively sealed himself off from discovering many important electrical phenomena; thus he has uncovered little fundamental information about the universe from his electrical studies.(4)

In 1950 Alfvén published *Cosmical Electrodynamics,* the work in which he explored the field left to him after he had thus narrowed his horizons. Early in his book he focused his attention briefly on electrical discharge processes and listed three different regions that can be discerned in most discharges:

"1. The cathode region, where the electrons (which carry the main part of the current) are produced by emission . . .
2. The anode region (which is rather unimportant) associated with the passing of the current between the discharge and the anode.
3. The 'plasma' which extends from the region of the cathode mechanism to that of the anode mechanism. The properties of the plasma can be regarded as characteristic for a gaseous conductor in the absence of disturbances from electrodes.

The distinction between the different types of discharges lies mainly in the cathode mechanism . . ."(5)

It seems singularly unfortunate that Alfvén chose to include the parenthetical remark that the anode region is unimportant. He thus led himself and his readers to ignore a vast field of inquiry with unknown potentialities. It may be fair to say that anode phenomena have, in the past, received less than their share of curiosity on the part of investigators; Somerville remarks that "there is . . . less reliable data concerning the anode than the cathode, probably because the anode region is usually not considered to be as interesting or as important to the maintenance of the [discharge] as the cathode region".[6] But the reasoning that leads to the conclusion that the anode region is unimportant in its own right is readily countered.

Electrons, by virtue of their lesser mass and higher mobility compared with positive ions, usually initiate discharges and ordinarily carry a disproportionate share of the current. On this basis, apparently, it is assumed that the source of the electrons is more essential, and hence inherently more interesting, than the anode. The shortsightedness of such reasoning may be demonstrated simply by pointing out that cathodeless discharges are not unknown.

The primary purpose of this paper is to suggest that the Sun is powered by a cathodeless discharge. But other examples are well known.

Transmission lines carrying high-voltage direct current – electric trolley wires, for example – discharge almost continuously to the surrounding air. In the case of a positive (anode) wire electrons ever present in the Earth's atmosphere drift toward the wire, attracted by its positive charge. As they penetrate the increasingly intense electric field close to the wire, the electrons gain energy from the field and are accelerated to energies great enough to initiate electron avalanches as they collide with and ionize air molecules. The avalanching electrons, in turn, intensify the ionization immediately surrounding the wire. Positive ions, formed in the process, drift away from the wire in the electric field. In this way, a more or less steady discharge is maintained, although there is no tangible object other than the surrounding air that can be considered a cathode.

Such a discharge is classed as a corona discharge. The region of intense activity close to the wire is referred to as the coronal envelope. And since so few "cathode" electrons are involved, and since they move so quickly through the outer region of the discharge, most of the current in this outer region is carried by the positive ions.

Clearly, discharge processes near such an anode wire are of at least as much "interest" as the charge-dissipating processes that take place in the surrounding air.

There has been evidence at hand for many years that the anode junctions of electric discharges harbor some rather remarkable phenomena and that these regions deserve much more attention than they have received in the past. In recent years a few investigators have begun to realize the true importance of anode *sheaths*. Particularly, Samuel Korman and Charles Sheer in the United States have directed scientific attention to the technical possibilities inherent in processes that characterize anode regions in high-intensity arcs. We have already written of the solar photosphere as an anode sheath,[7] and so we need not elaborate further here on this constituent part of the discharge.

The fundamental premise of the solar-discharge hypothesis is that a stream of electrons converging upon the Sun from all directions (or possibly, even probably, primarily in the plane of the planets) delivers the energy radiated by the Sun. In electrical-discharge terminology, if the Sun is an anode, the electric field driving the system is primarily confined to the region known as the cathode drop; and the energy gained by the electrons traversing this drop is that which must be cast off by the Sun in the form of radiation.*

The solar constant, defined as the total radiant energy at all wavelengths reaching an area of one square centimeter each minute at the Earth's distance from the Sun, is about 0.137 watts per square centimeter.[8] It works out, then, that the Sun must be emitting about 6.5×10^7 watts per square meter of solar "surface", and the total power output of the Sun is a (very nearly) constant 4×10^{26} watts.

The hypothetical electric discharge must then have a power input of 4×10^{26} watts.

Certain evidence – e.g., that of the cosmic rays, cited in *Pensée*[9] – leads me to suppose that the Sun's cathode drop may be of the order of 10^{10} volts, but this value is somewhat conjectural at this point. Let us claim, nevertheless, that this is the cathode drop. From this and the power requirement, we can calculate the total electron current required to fuel the Sun. (By analogy with laboratory glow discharges [see **Appendix I**], we may anticipate that most of the discharge current is carried by positive ions leaving the Sun; the loss of positive ions increases the net negative charge of the Sun, while only a comparatively few electrons crossing the cathode drop in the other

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*Additionally, the following proviso was added to the model by Juergens in his reply to Melvin A. Cook's comments in *Pensée IVR* III, p. 58: "To avoid the discomfiting assumption that the sun and the planets all started out with enormous positive charges that are now being whittled away, I have to conclude that the sun and the planets are not only negatively charged, but they are collecting more and more negative charge all the time. To explain why the sun does not quickly achieve balance with its galactic surroundings, I have to postulate continually increasing electrification in the galactic atmosphere, so that we have a steady-state situation in which the sun draws enough current to hold its own, but not enough to close the gap between its potential and that of galactic space." In the absence of this postulate, it can be calculated that the sun would "close the gap", or discharge completely, in less than a minute! – *CLE* direction deliver energy to the Sun. *The electric field between the Sun and the galaxy accelerates inflowing electrons and outflowing ions; this field is mainly confined to a small region near the Sun's surface and to a possibly larger remote region where the Sun's cathode drop occurs. The outflowing solar wind ions have such small velocities in comparison with the inflowing galactic electrons that despite their overwhelming numbers these ions do not drain significant energy from the Sun as they depart.* This is a concept that is somewhat difficult to accept at first, but it has been well substantiated in studies of electrical discharges.)

The *electron* current required, then, is the total power input divided by the cathode drop, or about 4×10^{16} amperes. Could such a current in any way fit the description "subtle radiation" – the energy transport mechanism rejected half a century ago by Eddington?[(10)]

. . . to be continued.

Appendix I: The Glow Discharge in the Laboratory and in Space

In 1930 and 1931, Irving Langmuir and co-author E. T. Compton published two long papers under the general heading *Electrical Discharges in Gases.*[(11)] These two works – "I. Survey of Fundamental Processes" and "II. Fundamental Phenomena in Electrical Discharges" – constitute "the classic review articles of the field", according to Cobine.[(12)] It seems appropriate, therefore, to quote at some length from the introductory paragraphs of the second of these papers; these afford a degree of insight into discharge phenomena that is seldom to be derived from the writings of later authors:

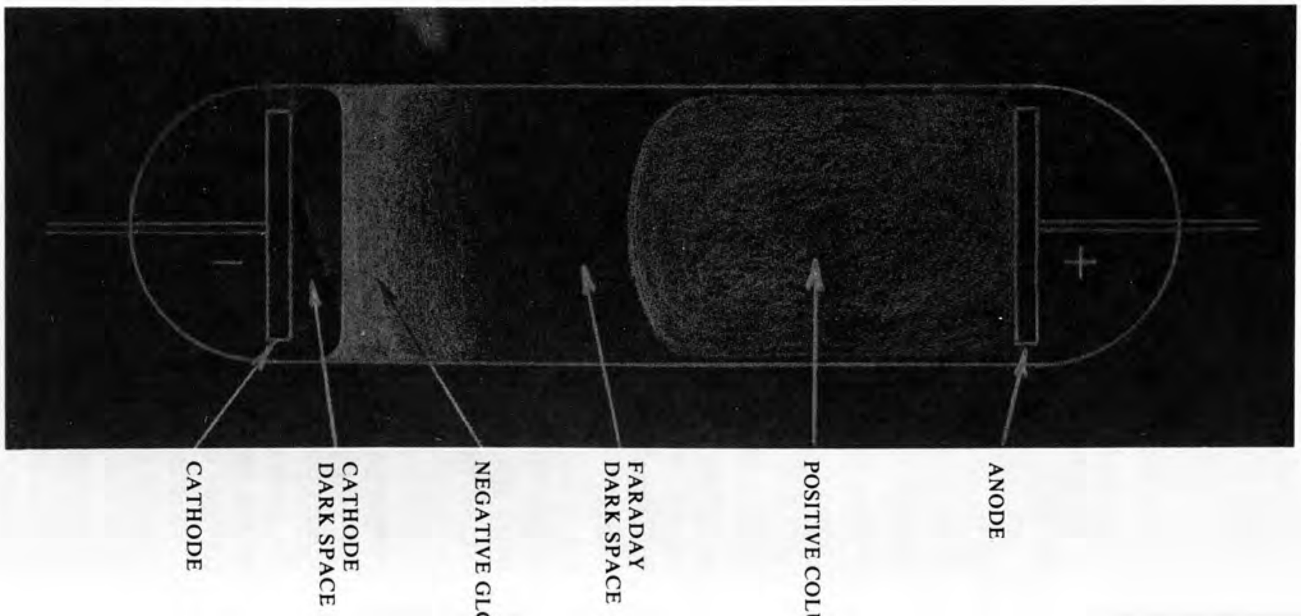
"Long prior to the beginning of the present century, certain types of electric discharge had been very extensively investigated. The typical phenomena that had been most frequently observed were those produced when a current was passed between two disk-shaped electrodes placed at some distance apart along the axis of a tube containing gas at a given pressure. The general effects of altering the pressure or the distance between the electrodes were well known.

"Figure 34 [here *Fig. 3*] illustrates a typical discharge of this kind. Close to the surface of the cathode a glow, called the cathode glow, is observed. Beyond this is the cathode or Crookes' dark space. Then comes the negative glow which is usually of considerable intensity. Passing in the direction toward the anode, the intensity of this glow gradually decreases and becomes a second dark space, called the Faraday dark space, this usually being several times wider than the cathode dark space. Then comes the positive column which begins

Figure 3

Glow Discharge Phenomena

"Close to the surface of the cathode a glow, called the cathode glow, is observed. Beyond this is the cathode or Crookes' dark space. Then comes the negative glow which is usually of considerable intensity. Passing in the direction toward the anode, the intensity of this glow gradually decreases and becomes a second dark space, called the Faraday dark space, this usually being several times wider than the cathode dark space. Then comes the positive column which begins at a definite position called the 'head of the positive column.' This space of demarkation is convex on the side toward the cathode. In most cases the positive column is of uniform density all the way to the anode. Sometimes, however, it is broken up into striations, which appear to consist of alternations of Faraday dark spaces and short sections of positive column. Close to the anode, especially if this is of small size, there may be an anode glow." *(after Langmuir and Compton.)*



sharply at a definite position called the 'head of the positive column.' This surface of demarcation is convex on the side toward the cathode. In most cases the positive column is of uniform intensity all the way to the anode. Sometimes, however, it is broken up into striations, which appear to consist of alternations of Faraday dark spaces and short sections of positive column. Close to the anode, especially if this is of small size, there may be an anode glow.

"Typical phenomena such as those illustrated in Fig. 34 are usually observed most readily at gas pressures in the neighborhood of one millimeter of mercury. At any given pressure the positions of the negative glow, the Faraday dark space and the head of the positive column are fixed with reference to the cathode. Thus, for example, if the anode is moved, these positions do not change, whereas, if the cathode is moved, these boundaries move with it. As the distance between the anode and cathode decreases, the anode may reach the head of the positive column so that the positive column disappears. In a similar way, the anode can be moved through the Faraday dark space and even into the cathode dark space. If the pressure is lowered, these distances from the cathode all increase approximately inversely apportional to the pressure. Thus with fixed distances between the electrodes, on lowering the pressure, the cathode dark space expands until it reaches the anode. The discharge then becomes one of a type studied particularly by Sir William Crookes. It was the study of such Crookes' tubes by Roentgen in 1895 that led to the discovery of x-rays.

"At high pressures, the cathode dark space and Faraday dark space move so close to the cathode that they become practically invisible and the whole tube is thus filled with the positive column. Gradually, with increasing pressure, the positive column detaches itself from the walls of the tube and becomes arc-like in character.

"Discharges of [this kind] are usually referred to as glow discharges. Many other types of discharge have been observed, for example, spark discharges, arcs between carbon or metallic electrodes at atmospheric pressure, corona discharges and the low current discharges observed when gases are rendered conducting by x-rays or radioactive materials.

". . . with electric discharges in very high vacuum where the current is carried by particles of one sign only (unipolar discharges) and where the carriers of the electric current pass across the vacuous space from one electrode (emitter) to another electrode (collector) without suffering loss of energy or change in momentum by collisions with gas molecules [it is unnecessary] to consider the generation of ions and electrons by collisions with gas molecules, [or] the recombination of ions and electrons.

". . . [When] current densities [are] so low that the number of charged particles present at any time in the space between the electrodes is so small that the electric field produced by them is negligible, . . . the potential distribution is practically the same as if no space charges were present . . . With higher current densities, the number of charged particles which carry the current becomes so great that the field produced by them can no longer be ignored and the potential distribution is then to be determined by a solution of Poisson's equation . . . Currents that flow under such conditions depend essentially on the presence of space charge . . .

". . . In the presence of very low pressures of gas, pressures sufficient to cause the generation of ions and electrons in space [by collisions between charge carriers and gas molecules], but yet so low that the motions of the resulting carriers are not appreciably interfered with by the presence of gas, . . . the electrons and ions which are generated in the space by electron impacts recombine on the walls of the tube and at the electrodes (but not in the space).

"Further consideration of the effects produced by the generation of ions and electrons in space will show that the potential distribution becomes such that a *potential maximum* develops in which low speed electrons are trapped. The accumulation of the trapped electrons causes a region to appear in which the space charge of the ions is neutralized by the electrons. We have named this part of the discharge the *plasma.* Near the electrodes and near the walls there are still regions where there are large space charges and where the conditions are still essentially those of a unipolar discharge in high vacuum. These regions of large space charge and intense electric fields are called the *sheaths.* They usually surround the electrodes and cover the glass walls . . .

"At still higher pressures, collisions of the electrons and ions with gas molecules profoundly modify their movements so that alterations are needed in the space charge equations and in the equations which determine the distribution of potential within the plasma. Recombinations of ions and electrons may then also occur in the body of the gas and lead to important changes in the conditions."

It is important to note the physical distinctions that are drawn here between regions of plasma and sheaths. A plasma is a region in which positive and negative space charges are approximately equal and strong electric fields are absent. A sheath is a region characterized by imbalance between positive and negative charges, so that strong electric fields are set up. Langmuir introduced these terms in the 1920s. In the present and following works, his definitions for them will be adhered to whenever plasmas and sheaths are discussed.

Having looked at the phenomena associated with a glow discharge, we are now in a position of attempting a more detailed analysis of the phenomena in space arising should our basic postulate be true, that the Sun is the anode end of a cathodeless discharge extending from the perimeter of the solar system.

NOTES AND REFERENCES

1. J. C. Maxwell, *A Treatise on Electricity and Magnetism* (1873; 3rd ed. 1891; Dover, 1954), p. 61.

1a. R. E. Juergens, "Plasma in Interplanetary Space: Reconciling Celestial Mechanics and Velikovskian Catastrophism," *Pensée IVR* II (Fall 1972), pp. 6-12; *Velikovsky Reconsidered* (N. Y., 1976), pp. 137-155. First presented at the Lewis & Clark Symposium, Portland, OR, August 15-17, 1972.

1b. I. Velikovsky, *Cosmos Without Gravitation* (N. Y., 1946); *Worlds in Collision* (N. Y., 1950).

1c. M. A. Cook, *Quasi-lattice Model of Plasma and Universal Gravitation* (Univ. of Utah, 6/2/58), Bulletin Vol. 48, No. 18 (also Bulletin No. 93 of the Utah Engineering Experiment Station); "Bands in Solids and Their Influence on Thermal Expansion and Compressibility," Appendix III in *The Science of High Explosives* (N. Y., 1958), see especially pp. 420-426.

1d. C. E. R. Bruce, *A New Approach in Astrophysics and Cosmogony* (London, 1944); "Terrestrial and Cosmic Lightning Discharges" in *Recent Advances in Atmospheric Electricity*, L. G. Smith, ed. (London, 1959), pp. 461-468; "The Extension of Atmospheric to Space Electricity" in *Problems of Atmospheric and Space Electricity*, S. C. Coronti, ed. (N. Y., 1963), pp. 577-586; "Lightning, Novae, and Quasars," Letter to *Nature* **209**, 798 (2/19/1966); "Successful Predictions of the Electrical Discharge Theory of Cosmic Atmospheric Phenomena and Universal Evolution," *Electrical Research Association* (Leatherhead, 1968), Report No. 5275; and many others.

1e. His theory assumes that cosmic processes involve the redistribution of electrical charges between bodies bearing different levels of *one* of the electric charges. Locally, that charge is chosen to be a "surplus" of electrons. Thereby all of the bodies within the solar system are considered to carry some surplus of electrons. This local "surplus", however, also turns out to be a "deficiency" of electrons on the galactic scale. Any electric interaction between the galaxy and the solar system produces an electric current which takes ions to the galaxy and bring electrons to the Sun and its satellites. Such an interaction, Juergens claimed, was the source of the Sun's radiant power. By it, the Sun's charge level is brought continually closer to that of the galactic environment around the solar system.

1f. R. E. Juergens, "Galactic Space Charge and Stellar Ene gy," *SIS Review* I:4 (Spring 1977), pp. 26-29; "S.I.S. vs Ralph Juergens", *SISR* II:2 (December 1977), pp. 46-51.

1g. R. E. Juergens, "Stellar Thermonuclear Energy: A False Trail?", KRONOS IV:4 (Summer 1979), pp. 16-25; plus Editor's Note by L. M. Greenberg, *Ibid.*, pp. 25-27.

1h. R. E. Juergens, "The Photosphere: Is it the Top or the Bottom of the Phenomenon We Call the Sun?", KRONOS IV:4, pp. 28-54.

1i. R. E. Juergens, *Pensée* II, *op. cit.*, p. 11.

1j. R. E. Juergens, *SISR* I:4, p. 28. He assumed a disc-like solar wind sheet, only two solar diameters thick at the Earth's orbit, to arrive at this (order of magnitude) estimate. Based upon measurements made by several space probes, the actual wind sheet is much thicker. At thirteen solar diameters above or below the ecliptic, the density of the solar wind is reduced by about 37% around the time of sunspot minimum; toward maximum there is little difference in the density with latitude (over the range noted here). See M. Dobrowolny and G. Moreno, "Latitudinal Structure of the Solar Wind and Interplanetary Magnetic Field," *Space Science Reviews 18,* 685-748 (1976), especially pp. 690 and 693.

1k. R. E. Juergens, KRONOS IV:4, pp. 28ff. [Also see E. R. Milton, "The Not So Stable Sun," KRONOS V:1 (Fall 1979), pp. 64-78. – *LMG*]

1l. A "cool" plasma is one where the drift velocity, imposed upon the plasma by the local electric field, is small compared to the random velocity (of the ions or of the electrons) characteristic of the temperature of the plasma.

2. I. Velikovsky, "An Answer to My Critics", *Harper's Magazine* (June 1951).

2a. Unless the star's properties are intrinsic – that is, they depend only upon its contents, "mass", "charge", etc. – the usual equations employed to quantify the transactions it undergoes may not remain simple, nor soluble. If, for example, the Sun's mass is determined not only by the number of atoms it contains, but in part from its location within the galaxy (environment), then the place at which the Earth must orbit the Sun – while retaining its present momentum in orbit – would vary as the Sun's mass "changed". Such a varying interaction can be neither anticipated nor excluded even with thorough knowledge of the Earth's motion in the present.

3. The term "radiation" is applied much more loosely today than in the past; almost any sort of material-particle or pure-energy emission is now spoken of as radiation.

4. The consequent restriction of his vision was not unrewarded, for Alfvén blazed a trail to the new science of magneto-hydrodynamics – the study of interactions of magnetic fields with ionized gases. It eventually resulted in Alfvén sharing the Nobel Prize for Physics in 1971.

5. H. Alfvén, *Cosmical Electrodynamics,* p. 38.

6. J. M. Somerville, *The Electric Arc* (1959), p. 87.

7. R. E. Juergens, KRONOS IV:4, pp. 28ff.

8. R. C. Willson, *Journal of Geophysical Research, 83,* 4003-4007 (1978).

9. R. E. Juergens, *Pensée* II, *op. cit.,* p. 11.

10. A. S. Eddington, *The Internal Constitution of the Stars* (1926; Dover, 1959).

11. *Reviews of Modern Physics, 2* (2) (1930); (2) (1931). Together, these two papers comprise almost 200 pages of Volume 4 of the *Collected Works of Irving Langmuir* (1961).

12. J. D. Cobine, in the Introduction to Vol. 4 of Langmuir's *Collected Works.*

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ELECTRIC DISCHARGE AS THE SOURCE OF SOLAR RADIANT ENERGY*

(CONCLUDED)

RALPH E. JUERGENS

We have advanced the premise that the kinetic energy of the electrons in a stream converging upon the Sun is the source of the energy thrown off by solar radiation. With a cathode drop of 10^{10} volts, each electron in the stream will arrive at the Sun with kinetic energy in the amount of 10^{10} electron-volts. If these electrons were not moving close to the speed of light we would expect about 2.4×10^{35} electrons (originating in interstellar space – not including those liberated by the ionization of solar atmospheric gases) to reach the Sun each second.

That the electrons impinge upon the Sun with velocities which are relativistic reduces the number of electrons which must arrive to supply the energy to power the Sun. Although the product of V *(the cathode drop) times* e *(the electron charge) equals the kinetic energy of the current carriers, the acceleration of the galactic electrons within the solar discharge to velocities which approach the velocity of light causes effects not seen in more mundane discharges. From calculations simulating the behavior of electric currents produced by relativistic electrons it seems as if the discharge current delivered has a limit – it does not continue to increase as the accelerating potential is raised to very large values. But an ever increasing potential can deliver linearly more energy to the discharge although no proportional increase occurs in the discharge current. The electrons which deliver the charge have become increasingly heavier than electrons at rest as their velocities asymptotically converged upon the velocity of light (see* **Appendix II***). These relativistic electrons seemingly deliver "extra energy" to the electric discharge through their increased mass.*[12a]

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In spite of the enormous absolute potential we attribute to the solar environment,[13] there is no reason to expect interstellar space to be characterized by important potential gradients, at least not on a scale of star-to-star distances. Even if currents flow in the spiral arms of the galaxy as Bruce suggests, to a good approximation the potential should be uniform in all directions within a few light-years of the Sun.[13a]

On this basis we could assume that most particles of matter indigenous to this region – neutral atoms and molecules, positive ions, and electrons – move in essentially random directions. The gas comprising these particles ought to behave as a thin, weakly ionized plasma.

It would follow, then, that the electrons eligible for capture by and participation in the solar discharge would be those whose random motions caused them to encounter the fringes of the electric field in the cathode drop of the discharge. The number of such electrons would be determined by the density of free electrons in space, the kinetic temperature of the plasma, and the size of the (spherical) region occupied by the solar cathode drop. But a calculation based on this approach would indicate that vast numbers of electrons should pour into the Sun.

Let us suppose that the effective velocity of a typical interstellar electron would be about 10^5 meters per second, corresponding to a kinetic temperature of a few hundred degrees Kelvin. From current estimates of the state of ionization of the interstellar gas, we might conclude that there should be as many as 50,000 free electrons per cubic meter.[14] The random electric current of these electrons then would be $I_r = NeC/4$, where N is the electron density per cubic meter, e is the electron charge in coulombs, and C is the average velocity of the electrons.[15] Using the given values, we find that the random electric current density should be about 2×10^{-10} amperes per square meter through a surface oriented in any given manner.

As we shall see later, the solar wind current noted at the Earth's orbit, when diluted by expansion to the postulated distance for the "edge" of cathode drop, is an order of magnitude below this estimate of the random electron current density (of 2×10^{-10} amperes per square meter). Can the discrepancy between electric theory and satellite observations be reconciled and understood in terms of other yet to be considered environmental factors – such as the Sun's galactic classification and/or its location within the galaxy?

THE TWO POPULATIONS OF STARS

Since we are postulating that stars are powered by electric currents flowing from the stars to their surroundings, we should examine the stars of the galaxy and the nature of their galactic environments.

One of the most significant discoveries of the past few decades was that of Walter Baade of the Mount Wilson and Palomar staff. He was the first to recognize that the stars of the local galaxy fall into two general classes: Population I stars, of which the Sun is an example, are found mainly in the flattened disk of stars that dominate the outer part of the galaxy; they range in color from red to blue, with giant stars at both extremes, the blue ones being by far the brightest. Population II stars are found in globular clusters – "satellite systems which surround our Milky Way, apparently hedging it about in all directions"[(16)] – and in great numbers in and about the galactic nucleus; the brightest stars of Population II are less brilliant than the blue giants of Population I and they are red in color, but brighter than the giant red stars of Population I.

It was soon noticed in studies of our own and other galaxies that Population I stars are present only in regions where there is dust. This dust is richer in metals than the typical interstellar gas, and the Population I stars seem to have a higher admixture of metals than those of Population II. Therefore, the consensus among astronomers is that the two populations represent two different age groups, the older stars of Population II having been formed from an earlier blend of ingredients, before metals were as abundant in the universe as they are now. The basic difference in the two populations is accepted to be one of metal content.

But the primary observational fact is this: "where there is no dust, there is no Population I."[(17)]

The Sun as a Population I star ought to be typical of its group. By examining its operation we might be able to draw some conclusions about the state of electrification of the dusty galactic disk. We start by considering the Sun surrounded by a sphere of space through which it draws energy from, and discharges current to, the galaxy.

The total electron current that can be drawn by the discharge is the product of the random current density and the surface area of the sphere occupied by the cathode drop. There is little to indicate how large this sphere might be, but in view of the enormity of the cathode drop it seems likely that the radius of the sphere would be large in terms of solar system dimensions. The mean distance of Pluto's orbit is 39.5 astronomical units, or about 6×10^{12} meters. We might guess that the cathode drop would reach to at least 10^{13} meters from the Sun, so that its spherical boundary would have a collecting surface area of somewhat more than 10^{27} square meters.

Such a surface could collect a current of interstellar electrons amounting to practically 10^{18} amperes – twenty-five times greater than the total current that seems proper. And of course a larger sphere could collect an even greater current.

If the hypothesis is to be valid, we can only conclude that free electrons are extremely scarce in the interplanetary medium.

This, of course, is not in conflict with the ideas embodied in the suggested model of the galaxy; we postulated initially that free electrons must be overly abundant in the nucleus and positive ions overly abundant in the outer regions. Still, what we conceived was an imbalance in relative numbers, not an absence of one or the other type of particle in any absolute sense. If atomic matter is present, we must expect ionization to occur to some significant degree, and electrons must therefore be liberated in space. What happens to them?

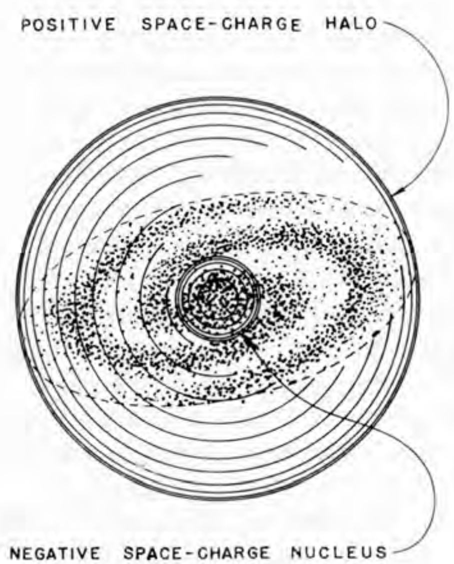

Figure 1

The Galaxy and Its Electric Space-Charge

A non-uniform distribution of space-charge in the galaxy at large could provide the driving potential for stellar electrical discharges. Such a galaxy has a spherical shell of positive space-charge at its outer limit and a uniform negative space-charge throughout the remaining volume of the galaxy. So modeled the galaxy provides a negative space-potential sufficient to sustain the solar discharge.

One possible explanation for a dearth of free electrons in interstellar space suggests itself: The electrons may attach themselves to passing dust particles and thus become immobilized.[17a]

We have just speculated that cosmic dust may be filtering free electrons out of the interstellar gas and preventing them from flooding in upon the Sun. It is interesting to entertain the idea that the two populations of stars may differ fundamentally in the matter of current carriers in the cathode drop.

If, as suggested, the Sun and other Population I stars exist in an environment of electron scarcity, we must suppose that the discharge currents in the cathode-drop regions of these stars are carried predominantly by positive ions travelling outward. Population II stars, existing in regions where dust is not available to immobilize free electrons, may draw intense currents of electrons from their surroundings.[17b]

As a result of the galactic electrical structure proposed earlier,[18] *the galaxy will be ion-rich at its periphery and electron-rich toward its center. The effect will produce a local space-charge which varies from place to place within the galaxy, as depicted in Fig. 1. The galaxy so electrified can be viewed as a larger sphere of positive charges superposed upon a smaller sphere containing negative charges. The result is depicted at the top of Fig. 2. The electric potential associated with the spheres – separately and combined – is shown at the bottom of Fig. 2.*[18a]

The curvature of the potential distribution line in *Fig. 2* is suggestive in this connection. Wherever such a curve is convex upward, one can immediately infer that the region represented is one of positive space charge. Where it is concave upward the curve marks a region of negative space charge. (We have of course postulated that the galactic halo harbors excess positive charge and the nucleus excess negative charge, and this is what the curve depicts.) It seems conceivable that, in the nucleus, electrons might be so abundant as to charge dust particles and power stars at the same time. And if dust is absent, as seems to be the case in some regions, all free electrons could be available to the stars.[18b]

The evidence is sparse, and we can only speculate as to its meaning, but in a tentative sort of way we may conclude that the two populations of stars present no immediate obstacles to the electric discharge hypothesis.

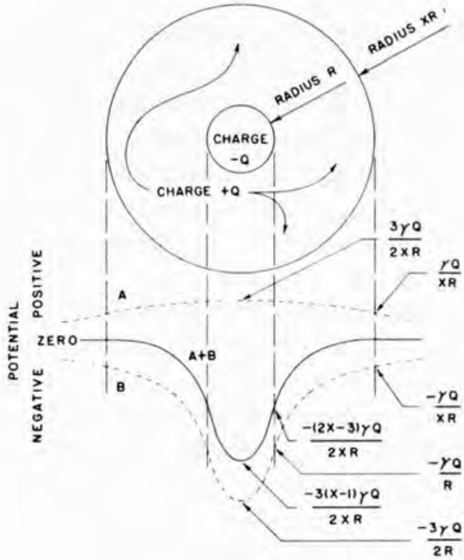

Figure 2

Hypothetical Charge Distribution Within the Galaxy

If the galaxy is seen as two superposed spheres of opposite electric charge, the negative charge confined to a sphere of radius R and the positive charge within a larger sphere of radius XR, then an electric potential function can be computed across the galaxy. Above, the two charged spheres are shown. Below, are the potential curves for the positively charged-sphere (A), the negatively charged-sphere (B), and for the sum of the two spheres (A + B). The constant γ has the value 9×10^9 in the meter-kilogram-second units. The charges (+Q, -Q) and the radii of the spheres containing them (R, XR) are presently undetermined. *(See reference f for numerical estimates of these parameters.)*

THE SOLAR DISCHARGE

We can picture the solar system as a region in space dominated by a continuous electric discharge, the Sun. To do so we start with the idea of an electrical cavity, a sort of "flaw" in the fabric of the Milky Way Galaxy. From our point of view this cavity has almost incomprehensibly grand proportions, but – from the viewpoint of its scale and importance in the galaxy – it is a minor, localized disturbance. At the center of this electrical "flaw" is a rather ordinary star, which is induced to absorb great quantities of electrons and spew forth in all directions protons, positive ions, and electromagnetic radiations of every kind.*

There is a higher electric potential near the Sun than in the galactic medium; hence the Sun accepts currents of galactic electrons and functions as an anode. The wall of the imaginary cavity therefore becomes

*For a complete discussion of the situation, see the editor's footnote at the bottom of p. 8 in KRONOS VIII:1.

the "emitter" of electrons, or the cathode.

Instruments carried into space have shown that there is a "solar wind" of protons and other positive ions blowing outward continuously from the Sun. Thus we must assume that the total discharge current is carried by particles of opposite charge moving in opposite directions – electrons toward the Sun, and protons away from the Sun. If we assume that the electrons in the undisturbed galactic medium move – for all practical purposes, in random directions – it follows that, at the cavity "wall", the current must be carried almost entirely by protons. At the surface of the Sun, on the other hand, we may assume that the protons start to move outward with almost negligible velocity, so that the current into the anode is carried entirely by electrons. From these considerations we shall be able to arrive at some sort of estimate of the size of the hypothetical discharge cavity.

In form, the discharge would seem closely analogous to a corona-like discharge from a positive point. Cobine points out, however, that the term corona, by convention, is applied primarily to discharges at relatively high gas pressures in the terrestrial environment.[19] In the Sun's atmosphere, gas pressures are everywhere low by earthly standards, so it will be convenient to discuss our model in terms usually applied to low pressure glow discharges, bearing in mind, however, the spherical geometry imposed by our first postulate.

Still, as we shall see, there are compelling similarities between phenomena observed in corona discharges and phenomena observed in the atmosphere of the Sun. In any case, the corona discharge is acknowledged to be a form of glow discharge, differing principally in geometry from the glow discharges that are studied in cylindrical discharge tubes. Thus, it is a matter of no great concern that we choose to analyze the solar discharge in glow discharge terms rather than in terms of corona discharges.

At the outset we should note certain factors that must tend to introduce complications and, hence, invalidate certain analogies to varying degrees. Perhaps the most important of these is the gravitational field of the Sun, especially insofar as it affects gas densities in different regions of the postulated discharge.

For reasons that will soon become clear, the postulated discharge – though focussed on a central solar anode – would appear to embrace a vast region of space, most of it devoted to cathode mechanisms. The solar corona, and its extension through interplanetary space and beyond, finds an analog in the "negative glow" region of a glow discharge. The chromosphere we shall interpret as the inner limit of this negative glow. Only the photosphere, at the inner limit of the vast discharge cavity, will be assigned an anode function in this model.

The focus of the discharge is the Sun itself, an anode serving as both a source for positive and a sink for negative charge carriers. The flow of such carriers between the interstellar medium and the Sun constitutes the electric current that powers the Sun.

As already indicated, an implicit assumption of the solar-discharge hypothesis is that galactic electrons flow toward the Sun in a stream moving counter to that of the solar protons. This is clearly incompatible with Parker's hypothesis[20] – the source of the term "solar wind". In his view, which is widely accepted, solar plasma comprising both protons and electrons moves outward in an unending stream from the Sun. Up to now, however, with Parker's assumption implicit in their design, most deep-space probes have sampled only the proton flux, and the drift of electrons has been assumed to correspond to the drift of positive ions.[21]

The sunward currents of electrons that are all-important to the present hypothesis might be investigated with suitably designed space probes, especially since preliminary calculations (see below) suggest that these currents in the vicinity of the Earth would be carried by electrons moving at (very nearly) the velocity of light. Detection may be made difficult, however, by the fact that such fast electrons quickly charge up the detecting instruments to the point where they repel electron currents. Probes of presently feasible proportions may be unable to carry apparatus sufficient to maintain suitable potentials on electron detecting devices, such as the Faraday cup.

The surface of a sphere with a radius equal to that of the Earth's orbit is 2.8×10^{23} square meters. An electron current of 4×10^{16} amperes crossing through such a total area with uniform distribution yields a current density of 1.4×10^{-7} amperes per square meter, a value that can be achieved if the interplanetary medium contains something less than 3,000 relativistic electrons per cubic meter streaming toward the Sun.

Satellite measurements give an electron population in the local plasma of 9 to 11 per cubic centimeter,[22] which amounts to 9 to 11 million per cubic meter. (The discharge hypothesis suggests that most of these are *secondary electrons* generated by the ionization of solar gases.)

On the average, measurements show that most of these detected electrons are moving neither inward nor outward. Parker's model requires that a like number of electrons and ions drift outward, constituting the electrically neutral solar wind. Here, we require that an inward flux of 3000 relativistic electrons per cubic meter pervades *the background of 9 to 11 million electrons per cubic meter which occupy, but do not flow through, the space between the planets of the solar system.*

On this basis, we are at least partially justified in supposing that the negative glow of the solar discharge cannot be located outside the Sun's atmosphere. Since the negative glow is the first true plasma region to be encountered as we proceed from the cathode of a glow discharge toward the anode, the interplanetary plasma may be tentatively assigned this role without straining the self-consistency in the model.(23)

Thus it would appear that, if but one in about every 3,000 electrons near the Earth turned out to be a current carrier moving at almost the speed of light toward the Sun, the power delivered would be enough to keep the Sun "burning" at its present rate. This seems a rather subtle stream but it would suffice to power the Sun.

Appendix II: Relativistic Electrons and Protons

The theory of relativity says that the maximum possible velocity for transporting matter or energy is the velocity of light, $c = 2.998 \times 10^8$ m/sec. Under ordinary (low potential) conditions, the work done on an electron charge e that is accelerated through a potential drop of V volts is Ve. In empty space where the electron suffers no collisions, this work is converted entirely into kinetic energy, or energy of motion at velocity v amounting to $\frac{1}{2}mv^2$. Here m is the mass of the electron. The equation that expresses these facts is $Ve = \frac{1}{2}mv^2$. From this, we see that the velocity of the electron is given by $v = (2\ Ve/m)^{1/2}$. If we try to apply this equation to the extremely high voltages, however, we run afoul of the theory of relativity; for example, a voltage drop V of the order of 10^6 volts would yield a velocity for electrons far in excess of c.

Relativity theory gets around this sort of problem by saying that as a particle approaches the velocity of light its *effective* mass, or inertia, increases. As electrons are accelerated to ever higher *energies,* the velocities slowly approach ever closer to that of light, while the effective electron mass goes up sharply. Theory and experiment indicate that the mass of an electron m_e travelling at velocity v exceeds the electron rest mass $(m_e)_o$ by a factor of $1/(1 - v^2/c^2)^{1/2}$; that is:

$$m_e = (m_e)_o \frac{1}{(1 - v^2/c^2)^{1/2}}$$

and, for protons travelling at relativistic velocities

$$m_p = (m_p)_o \frac{1}{(1 - v^2/c^2)^{1/2}}$$

The kinetic energy of a particle is the difference between its energy at rest with mass m_o and its energy when in motion with mass m and velocity v. The classical equation for kinetic energy, $Ve = \frac{1}{2}mv^2$, is actually only an approximation that is valid at low (non-relativistic) velocities. For high velocities the kinetic-energy equation must be modified to take into account the relativistic increase in particle mass. The result is Einstein's law:

$$Ve = m_o c^2 \left[\frac{1}{(1 - v^2/c^2)^{1/2}} - 1 \right]$$

It can be shown that for very low values of v/c -- which is to say, for non-relativistic velocities – Einstein's general equation yields results practically identical with the classical or Newtonian equation.

It is useful and instructive to portray the implications of the kinetic-energy equation graphically. We can do this by inserting arbitrary values for the ratio v/c into the equation, calculating the voltage drops V required to yield these ratios for particles of different rest masses, and plotting the results as a series of curves. Such curves for electrons and protons are shown in *Fig. 4*. The dashed lines labelled A and B show how curves derived from the classical equation of kinetic energy diverge from reality at high velocities.

Inspection of the kinetic-energy equation indicates that curves of the type shown in *Fig. 4* for any two kinds of charged particle will be displaced from one another on the potential-drop scale by an amount equal to the overall ratio between the individual mass-to-charge ratios. Thus, whereas an electron accelerated through a drop of 10^5 volts achieves a velocity of about $0.55c$, a proton – carrying the same charge, but 1836 times the rest mass of the electron – requires a voltage drop of 1.84×10^8 volts to reach a velocity of $0.55c$.

Additional relevant (and revealing) curves can be drawn by plotting the ratios m/m_o of relativistic mass to rest mass for both electrons and protons against the voltage drops required to yield such ratios. *Fig. 5* shows such curves for these two types of particle.

Both curves, of course, begin asymptotic to a horizontal line at $m/m_o = 1$, for the relativistic mass can never be less than the rest mass. The electron and proton curves approach being parallel at the upper

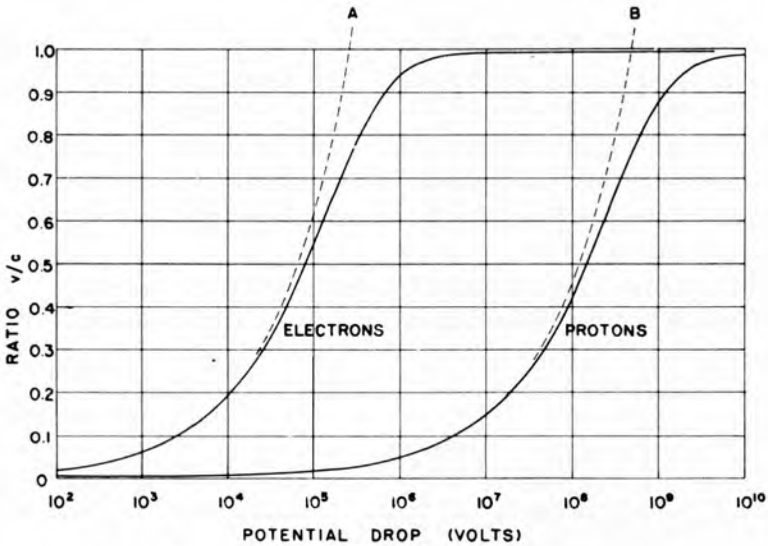

Figure 4

Velocities of Electrons and Protons Accelerated Through Great Electrical Potential Differences

The dotted curves labeled A and B are the velocity curves calculated using Classical theory. The solid curves include the correction for increased mass with increasing velocity in accordance with the Special Theory of Relativity.

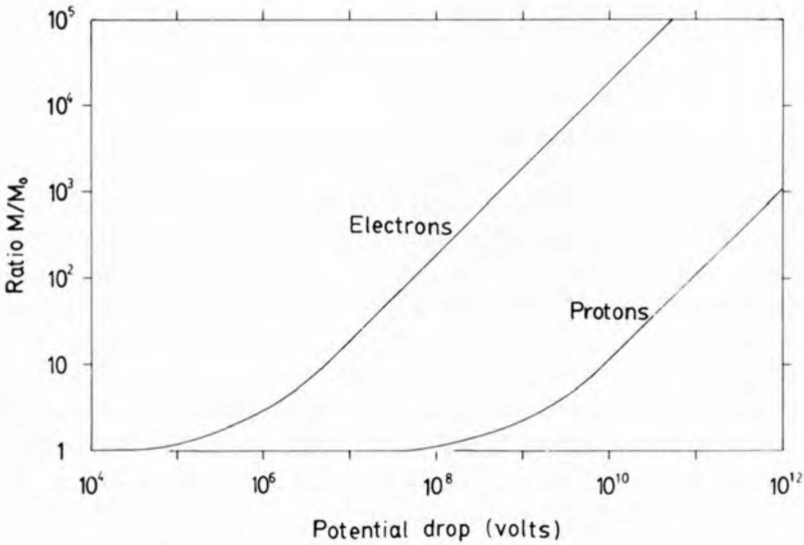

Figure 5

Mass Enhancement for Relativistic Electrons and Protons

When accelerated through great electrical potential differences electrons and protons asymptotically converge upon the speed of light **in vacuo.** Their great energies make them appear to have an enhanced mass (M) in comparison to their mass at rest (M_0). The ratio of their mass **in motion** to their mass **at rest** increases measurably with increasing energy above a specific "threshold" for each particle.

limit of the indicated voltage scale: *thereafter they differ by 1836; the electron mass has increased 1836 fold relative to the proton mass for the same energy.*

Now, let us again use secondary subscript symbols to differentiate between electrons and protons. Thus m_e and m_p will stand for the relativistic masses, respectively, and $(m_o)_e$ and $(m_o)_p$ will designate their rest masses.

If we read off the curves of *Fig. 5* at different values of V the corresponding values of $(m/m_o)_e$ and $(m/m_o)_p$, we can tabulate them as follows:

V (volts)	$(m/m_o)_e$	$(m/m_o)_p$	$m_p/m_e = 1836 \dfrac{m_p/m_e}{(m_p/m_e)_o}$
10^4	1.0	1.0	1836
10^5	1.2	1.0	1530
10^6	2.8	1.0	660
10^7	18.6	1.0	99
10^8	190	1.1	10.7
10^9	1900	2.1	2.03
10^{10}	19000	11.5	1.11
10^{11}	190000	110	1.06

Plotting these results (*Fig. 6*) we get a very interesting curve. As we would expect, for low voltage drops, the ratio between the proton and electron masses is the same as that between their rest masses. As we move upward to voltage drops where electrons, but not protons, increase steeply in relativistic mass, the ratio of the effective masses starts to decrease rapidly. But when we consider voltage drops of such magnitude that the proton effective mass climbs steeply, we find that the ratio of the effective masses of electrons as against protons traces a reversal of curvature and ultimately approaches a value of unity. Infinite voltage drops produce infinite relativistic masses for both types of particle. The limiting ratio of their masses (m_p/m_e) should be unity. But it is something of a surprise to find that same ratio achieves a value that is practically unity with a drop of only 10^{10} volts, the same value that we estimated for the cathode drop associated with the solar discharge! Could this just be a coincidence?

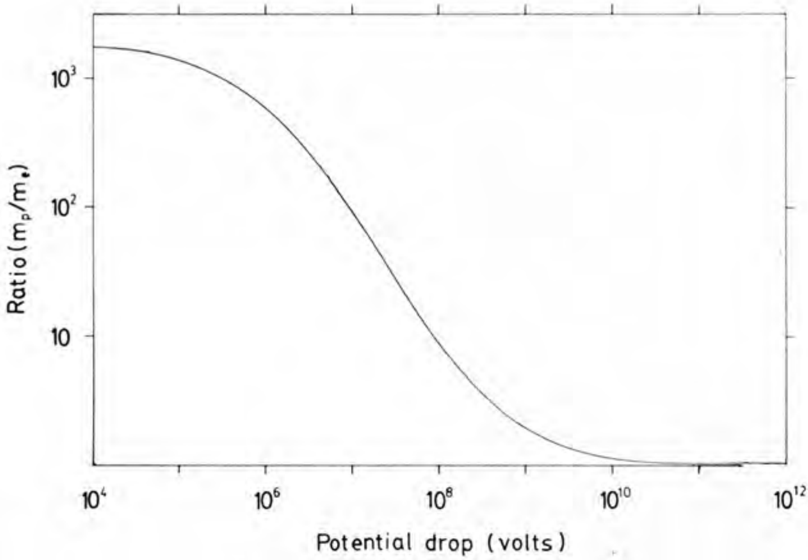

Figure 6

Comparison of Electron and Proton Masses at High Energy

At rest protons are more massive than electrons by a factor of 1836. Electrons moving with velocities which approach the **speed of light** become sufficiently "heavier" so their mass approaches that of slower moving protons having the same energy as the electrons.

Appendix III: Relativistic Electric Currents

by George Robert Talbott and Earl R. Milton

We wish to understand the current produced by electric potential differences on a galactic scale. We have postulated that galactic potentials can produce electric currents where the carriers (especially when they are electrons) may reach velocities which approach the *velocity of light* (see *Fig. 7*).

An electric current is the net charge flowing past a point (or through some small area) over an interval of time. It can be expressed in terms of the number ($\boldsymbol{n}$) of electron-charges (e) flowing:

$$n\,e = I\,t \qquad (1)$$

where I is the current (in charges per second) and t is the time in which those charges flow past some point.

It is also meaningful to know the number of charges along any unit of space, which we shall designate as η (charges per meter). With η, an expression can be produced relating the velocity of the current carrier (v) to the current (I)

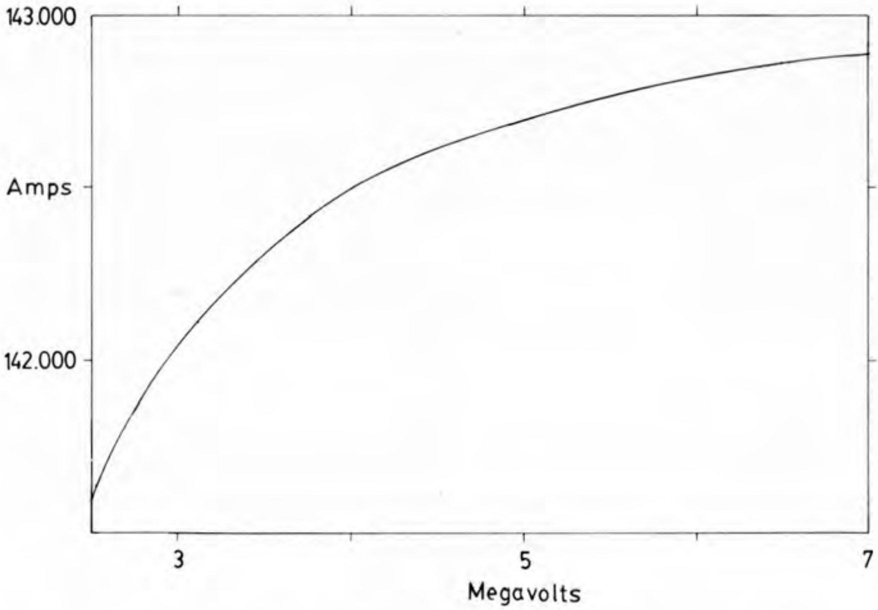

Figure 7

Current Produced by Field Accelerated Charged Particles

As the velocity of accelerating electrons approaches the **speed of light,** the current change produced by further acceleration decreases producing a current "limit" for the potential field which is producing the current.

$$I = \eta\, e\, v \qquad (2)$$

Now we may relate the current flowing to the potential difference using the energy relation

$$V e = \tfrac{1}{2} m v^2 \qquad (3)$$

where m is the effective mass of the current carriers, v is their velocity, and V is the accelerating potential.

For a relativistic velocity this becomes

$$V e = \tfrac{1}{2} \frac{m_O}{(1 - v^2/c^2)^{1/2}} v^2 \qquad (4)$$

in which m_O is the rest mass of the carriers, v is their velocity, and c is the *velocity of light in a vacuum.* Introducing current for the charge and velocity terms [using **(1)** and **(2)**] the equation becomes

$$\frac{V t}{n} = \tfrac{1}{2} \frac{m_O}{(1 - v^2/c^2)^{1/2}} \frac{I}{\eta^2 e^2}$$

or

$$V = \left\{ \frac{m_O\, n}{2t\eta^2 e^2 \;(1 - v^2/c^2)^{1/2}} \right\} I \qquad (5)$$

an equation which has the simple form of Ohm's law ($V = R\,I$) but is quite complex since both the η and v factors within the "resistance" term affect the current. Notwithstanding a *galactic resistance* term can be visualized from the coefficient

$$R = \frac{m_O\, n}{2t\eta^2 e^2 \,(1 - v^2/c^2)^{1/2}} \;.$$

As the velocity of the current carriers approaches c the circuit becomes infinitely more resistive in a complex way. The resulting *galactive resistance* allows self-limiting cosmic discharges to occur producing observed stellar luminosities.

Perhaps more informative is the re-expression of the energy relationship (4) in terms of the potential

$$V = \frac{m_O\, c}{2\,e} \; \frac{v^2}{(c^2 - v^2)^{1/2}} \qquad (6)$$

which can be evaluated by inserting various electron velocities. The accompanying currents can be obtained from equation (2). Their quotient gives the *galactic resistance* for the cosmic discharge circuit.

An alternative means of demonstrating the relativistic increase in electrical resistance is to rearrange equation (4) as follows:

$$v = \left\{ 2\left((b^4/c^4 + b^2)^{1/2} - b^2/c^2 \right) \right\}^{1/2} \qquad (7)$$

where $b = Ve/m_O$. The velocity so found can, by equation (2), be converted to an electrical current. The ratio of the potential to the velocity-deduced current is the relativistic resistance. This will be seen to rise with the velocity, just as expressed in the other equations. The alternative derivation is interesting, and allows an independent approach in which potential is stipulated first, and then the consequences are deduced.

NOTES AND REFERENCES

12a. The increase in mass with velocity is well accepted in physics. Until this phenomenon was discovered, the term "mass" had been associated strictly with the number of atoms present in a body (that is, it was strictly an intrinsic property). Acceptance of the notion that mass changes with velocity requires tacit acceptance of some extrinsic contribution to the body's mass. Extension of this concept to include the variation of mass with decreasing separation of cosmic bodies may soon occur. Admission that "electric charge" also varies because of extrinsic factors would be a further step in the right direction.

13. R. E. Juergens, "Galactic Space Charge and Stellar Energy," *SIS Review* I:4 (Spring 1977), p. 29.

13a. We can visualize the local electric environment as the superposition of two electric potential gradients. The larger is responsible for the existence of the Sun; we call it the discharge gradient. The discharge gradient exists between the perimeter of the solar system and the surface of the Sun. The smaller is the galactic gradient. It describes the change in electric potential encountered moving radially across the galaxy (from its center to the halo). Across the solar system, this galactic gradient would likely be linear and quite insignificant compared to the Sun's discharge gradient. We acknowledge the possible existence of some local difference in the galactic gradient with direction. The gradient perpendicular to the galactic equator (the Milky Way) could differ from those in the plane (along and across the galactic arm containing the Sun). Dominance of the Sun's discharge gradient would tend to obscure anisotropies in the galactic gradient.

14. S. A. Kaplan suggests (*Interstellar Gas Dynamics*, Pergamon, 1966) that about 5% of the interstellar gas is ionized and that the average density of this gas is about 1 atom per cubic centimeter (averaged across the whole galaxy).

15. I. Langmuir and H. Mott-Smith, *General Electric Review*, *27* (1924); Vol. 4, Langmuir's *Collected Works* (Pergamon, 1961), p. 25.

16. G. W. Gray, "The Universe from Palomar," *Scientific American* (Feb. 1952).

17. *Ibid.*

17a. Interstellar dust is believed to be the cause of the optical polarization of starlight. Though most astronomers will not admit that the dust grains carry electrical charges, they do maintain that the dust grains are probably lined up because of the presence of an interstellar field. See E. v. P. Smith and K. C. Jacobs, *Introductory Astronomy and Astrophysics* (Phila., 1973), p. 426.

17b. The galactic nucleus is at most 6500 light years in radius; it contains about five percent of the galaxy's mass, conventionally 10^{10} solar masses. *Ibid.*, pp. 456-457.

18. Juergens, *op. cit.*, pp. 27-28.

18a. The symbols used in this figure are the same as those given in Juergens' earlier paper. *Ibid.*

18b. The star density in the galactic nucleus is higher than in the disc of the galaxy, where the Sun is located. Using the data given in note 17b above, the stars in the nucleus region are about 3 light-years apart. Whether the galactic nucleus contains dust or not is unclear; see Smith and Jacobs, *loc. cit.* The multitudinous stars seem to be of low luminosity, yet x-ray and intense radio emission is detected from the region; to me these emissions, considered to be evidence of a highly active galactic nucleus, buttress Juergens' claim that there are many free electrons available to the often closely packed clumps of stars there.

19. J. D. Cobine, *Gaseous Conductors* (Dover, 1958), p. 252.

20. E. N. Parker, *Astrophysical Journal*, **128** (1958), p. 664.

21. Re Explorer X: Cf. W. S. Bridge, *Physics Today* (March 1963), p. 31; re Mariner II: Cf. M. Neugebauer and C. W. Snyder, *Science*, **138** (1962), p. 1095.

22. Cf. A. J. Hundhausen, *Space Science Reviews*, *8* (1968), p. 716; W. C. Feldman, *et al.*, *Journal of Geophysical Research*, *80* (1975), p. 4184. The electron density probably fluctuates over the sunspot cycle, as does the better studied proton density (see note 1j in KRONOS VIII:1, p. 13).

23. I. Langmuir, *General Electric Review*, *38* (10) (1935); *Collected Works*, Vol. 4, p. 191.