Cathode Spots and Pairs

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Electrospark phenomena occur at high flux, and at these fluxes vacuum arcs form cathode and anode spots, locations of very high current density. Since evidence of similar hot spots appear on electrospark electrodes, it is reasonable to consider these spots to be similar in nature to vacuum arc electrode spots, about which much is known. [1] The extreme temperature of electrode spots in an electrolyte, the clearly visible ejecta and luminescent area at the spot surface, are signs that the interior of the spots should be indistinguishable from those in a vacuum arc. The purpose here is to speculate on potential explanations for some poorly understood aspects of electrode spot mechanics, and possible application of the principles to the creation of useful devices.

The typical size for a cathode spot is about 0.1 micron.[1] There is much not fully understood about cathode spots. As of 1980, there were at least 17 major explanations for them. [2] There is also the continuing investigation of other emission anomalies under the "Pseudospark" classification. [3]

Of special interest about cathode spots is that metallic vapor jets issue from them with velocities of up to 1000 m/sec, with one atom of metal removed per about every 10 electrons emitted. [4] These spots can have high currents, estimated at up to 10^8 A/cm^2, and it is thought that the emission of high energy electrons is by thermal-field (T-F) emission as described by Schottky [5] and that the less energetic electrons are emitted by field emission (tunneling) It is thought most of the emission is T-F emission, but, as of 1980, there was no experimental proof of this. [6]

A calculation using Childs space charge equation shows a vacuum arc 1 cm long varying a current density of 100 A/cm^2 would require about 100 KV voltage, and that if 99 percent of the electron space charge were balanced by a distribution of positive charge, then 4800 V would be required. [7] Actually only 28 V is required, indicating the space charge is neutralized to within a few parts per million, and that this neutralization occurs at the cathode spot. "Flows of ions away from cathode spots toward the anode (against the main electric field of discharge) have been detected by both optical and mass spectrographic data." [7]

Lafferty and Dillon state: "Honig [8] and Franzen and Schuy [9] found large amounts of multiply charged ions as well as singly charged ions. Plyutto et al. [10] showed in addition that the average ion energies correspond to voltages exceeding the total arc voltage, thus the average ion has sufficient energy to move anywhere within the discharge. Davis and Miller [11] confirmed, extended, and made more precise those earlier measurements: they showed that the energies of the neutral atoms emanating from the arc are much less than those of the ions, and apparently are confined to thermal energies, except for a few forming a high energy tail of the distribution. In copper arcs the energy gap (measured at anode potential) between the average singly charged ion and the average neutral exceeds 30 eV. There is very little overlap between neutral atom and ion energy distribution." [12]

Arc voltage characteristics are poorly understood, and no published theory explains the positive resistance characteristic or tells why the arc voltage for molybdenum is higher than for copper. [13] It appears to the author to be especially true the voltages are poorly understood at arc extinguishing currents because of the extreme fluctuations, fluctuations many times arc voltage and at frequencies of 1 - 15 MHz, despite the addition of up to 2500 uH inductors in the circuit. [14] If such voltage fluctuations were the result of circuit parameters the addition of inductance would have changed the transient frequencies.

The combination of all these factors leads the author to hypothesize that pair formation may be going on in conductors at thermal levels. Due to thermal collisions, such pairs would have a very short half-life, and thus would not permit formation of any macro level coherence like that exhibited in superconductors. However, if such pair formation were frequent enough, it could account for some part of the above phenomena.

If there is pair availability in the cathode, then neutral atoms, boiled off the interior surface of the cathode spot hole, could be seeds for formation of doubly negative charged condensate formation, e.g. a Cu-- condensate formation. It is even possible that the pair formation and tunneling to a co-centered location with the seed atom occurs at the same instant. The essential conditions would only be that the electrons have equal but opposite momentum, within the binding energy for a pair, and be equidistant from the seed. There would only be the possibility of tunneling to nearly exact co-centering on the seed. However, this co-centered configuration, even though having a high potential energy due to the tunneling of the electrons through their coulomb barrier, represents a lowest energy configuration for the electrons, thus the high probability even though the volume involved is small.

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The formation of double negative ions provides a couple explanations. One, it explains how the metal ions are accelerated out of the hole. Another is that, when the ion reaches the boundary of the hole, it meets the full electrostatic field gradient of the plasma ball in front of the electrode. Acceleration here would destroy the condensate and a high energy explosion due to the mutual repulsion of the condensate electron pair would result. The energy of that explosion would quickly be dissipated in the plasma ball by collision. However, it has been experimentally observed that the plasma ball contains ions well above the total potential drop across the vacuum arc. [15] Lastly, it explains why the energetic group of metal atoms are positively charged positive ions, or even multiply charged positive ions, and yet going the wrong direction. That is because the energy of the electron repulsion at the moment of condensate breakdown is sufficient to knock one or two extra electrons off the metal atom, thus leaving it as a positive ion with higher momentum than the thermal neutrals. Perhaps these mechanisms can explain the very presence of the high energy plasma ball on the cathode.

The oscillations at near extinguishing voltages and currents could possibly be explained by the fact that when current is down the ion density is down and the electrons from the exploding condensates preserve their high kinetic energy longer. In fact, as current approaches zero, the mean free path can exceed the arc gap width. As heat in the spot drops a larger percentage of the current must be due to tunneling. This means a greater concentration of the explosive condensates should be formed, and upon reaching the surface of the spot hole their explosion could produce a strong negative pulse which (1) momentarily suppresses the potential in the spot hole, and (2) generates heating on the surface of the hole. These effects serve to reduce the current while shifting the mode more back to the lower voltage T-H type arc. Operating in that normal low voltage mode, however, the hole quickly cools and potential drops, repeating the cycle.

There are various devices which seem to gain energy from arc and abnormal glow current oscillations. If the hypothesis is true then perhaps the excess energy is coming from condensate explosion. These condensates are the result of concurrent tunneling of one or more electron pairs to a neutral atom or ion in the cathode vicinity, especially in cathode spot plasma. Since electrons tunnel in pairs across Josephson junctions as often as they tunnel singly, it is reasonable to expect a high pair tunneling rate even in a non-superconductor, although the number of candidate pairs in the medium may be extremely small. Due to the value of the present hypothesis in explaining otherwise seemingly impossible phenomena, it may be that candidate pairs in hot conductors have a larger population than might be expected.

A method of producing pair tunneling which is an alternative to electrode spot production may be to create and utilize a thin dielectric layer that assures that all electron current is tunneling current. It is of special interest that Al, for example, is coated with Al2O3, which is a very strong insulator, yet aluminum conducts very well through this very thin oxide boundary. By "conditioning" electrodes through operation at a high voltage, dielectric layers can sometime be created which do not conduct well below the operating voltage. This fact may permit creation of an electrode well suited for pair conduction at a desired energy level. The author has had positive results coating electrodes with CaO solutions using high voltage AC current prior to using high voltage DC electrolysis. It is unknown if the polarizing properties of calcite were involved in the dielectric layer so formed or affected the energy balance of the electrolytic cell. [16]

Lastly, electron pair tunneling may help explain low energy nuclear reactions, and the positive relationship of flux to the frequency of such reactions. Electrons tunneled to a condensate proton or deuteron can not be expected to have tunneled instantaneously into a stable waveform, thus may momentarily exhibit more of a particulate character than wave character. This production of a small negatively charged nucleus-electron condensate may then permit close nuclear approach and the electron catalysis of fusion. The rate of such catalysis would be a function of the electron pair flux, not the pair energy. The pair formation rate, however, is at least in part a function of voltage.

The tunneled electron pair would not be bound sufficiently to the nucleus to permit the condensate to make a very close approach to another nucleus without breaking the bond. However, once the bond is broken, the abnormally close electron pair may repel at such a large initial energy, that the deBroglie wavelength will remain small enough to perform the catalysis.

The existence of electron pairs in hot conductors is very speculative. However, this one speculation gives explanation to various otherwise unexplained phenomena, and suggests a wide variety of related regimes for experimental exploration.

Though far more speculative, similar pair tunneling of nucleii could also occur. The primary diffence would be that the large nuclear mass greatly reduces the expected tunneling distance. Since conduction in electrolytes is almost exclusively due to proton tunneling anyway, such an evironment may make the ideal place for nuclear pair condensation to occur in an anodic analog to the cathode spot. Such an analog would be the issuance of pairs of hydrogen nucleii pairs from the interior of a nano-sized electrolyte bubble. Such pairs would condense on a negative charged particle, and one source of such a particle would be a high voltage metal cathode. In a high voltage electrolysis cell the electrolyte surface in the cathode plasma sheath acts as an anode. Unlike the condensation of electrons, which does not involve a strong nuclear force, the condensation of a pair of hydrogen nucleii establishes a permanent fusion.

FOOTNOTES:

1. Lafferty and Dillon, "Vacuum Arcs", Wiley & Sons, 1980

2. Ibid, p.5

3. <http://www.ee.umd.edu/~rhee/pseudospark/geninfo.html> and other info obtained by www search on "pseudospark".

4. Lafferty and Dillon, "Vacuum Arcs", Wiley & Sons, 1980, p.9

5. W. Schottkey, "Ann. Phys." (Leipzig), 44, 1011(1914)

6. Lafferty and Dillon, "Vacuum Arcs", Wiley & Sons, 1980, p.122

7. Ibid. p.123

8. R. E. Honig, "Proceedings of the Twelfth Annual Conference on Mass Spectroscopy". Montreal, June, 1964, p. 233

9. J. Franzen and K. D. Schuy, "Z. Naturforsch," 20a, 176(1965)

10. A. A. Plyutto, V. N. Ryzhkov, and A. T. Kapin, "Sov. Phys - J Exp. Theor. Phys.," 20, 328(1965)

11. W. D. Davis and H. C. Miller, J. Appl. Phys. 40, 22212(1969)

12. Lafferty and Dillon, "Vacuum Arcs", Wiley & Sons, 1980, p.126

13. Ibid, p.153

14. Ibid, p.154

15. Ibid, p.302

16. Various postings by H. Heffner to vortex-l@eskimo.com on CaO electrolyte cells.