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Research Article

Scaling up the Lattice Energy Converter

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Abstract

Multiple Lattice Energy Conversion (LEC) devices and configurations have experimentally demonstrated the ability to self-initiate and self-sustain the production of a voltage and current through an external load impedance without the use of naturally radioactive materials. These results have been reported by the authors [1], [2], [3], [4] and replicated by independent researchers [5], [6], [7], [8], [9]. A video, [10] shows that a voltmeter and a resistance substitution box are all that is required to observe and measure LEC output which for this test produced several hundred nanowatts of power per square centimeter of working electrode surface area. Given the extraordinary nature of the LEC results, the importance of independent replications by multiple credible and respected scientists cannot be overstated. While the ability to self-initiate and self-sustain the production of a voltage and current through a load is a significant innovation, present experimental power densities are typically in the range of a few microwatts per square centimeter, output must be scaled up by 6 orders of magnitude to produce a few watts, and by 9 orders of magnitude to produce a few kilowatts. Based on a review of the literature and an analysis of experimental results, five focus areas have been identified to scale up the LEC. This paper examines each focus area and identifies possible actions to increase LEC power output.
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1. Introduction

Throughout history, many great discoveries resulted from mistakes or experiments that did not produce the anticipated results. Such is the case with the Lattice Energy Converter, (LEC). Initial experiments were designed to see if we could perform electrolysis through a dry gas by including radioactive sources to partially ionize the gas so a current could be conducted. However, analysis of these initial test results indicated that several orders of magnitude more conduction was being produced than that which the ions produced by the radioactive sources would support. Additional experimentation, in the absence of the radioactive sources, confirmed that when an electrode that had been codeposited with Pd-H was present, the gas was being ionized. This spontaneous ionization was not predicted for the gas densities,

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temperatures, and non-radioactive materials that were being used. A quote from *The Case-Book of Sherlock Holmes,* by Sir Arthur Conan Doyle states: "When you have eliminated all which is impossible, then whatever remains, however improbable, must be the truth." By following where our experiments were leading, we travelled from the improbable to the reality of the Lattice Energy Converter.

The evolution of the LEC began with experiments that produced surprising results including the realization that something was ionizing the gas between a pair of electrodes and those ions could be harvested to produce an electric voltage and current. Although the demonstrated electrical power levels were small, typically a few microwatts per square centimeter, these experiments were producing direct energy conversion.

The LEC has demonstrated the unexpected ability to spontaneously self-initiate and self-sustain the production of ionizing radiation without the use of naturally radioactive materials. This extraordinary discovery is supported by extraordinary evidence including our experimental results, peer reviewed papers [1], [2] presentations at international conferences [3], [4] and multiple independent replications by other scientists [5], [6], [7], [8], [9]. Although the demonstrated electrical power levels are small, experimental results indicate that multiple parameters can be optimized to increase the output. If successful, the LEC may address multiple critical applications including 'green' energy production, medical treatments, space applications, and applications yet to be identified.

In early experiments, JJ Thomson and E Rutherford applied an electric field between the electrodes to sweep out the ions that were being produced by a source of Röntgen rays. When there is a significant electric field, it is permissible to ignore the contribution that diffusion provides to the conductivity [11]. The first complete sets of equations known to the authors describing the gas dynamics of conduction including diffusion were "On a nearly saturated stream in an air space bounded by two concentric spheres" and "On approximately saturated currents between plane-parallel plates" by E Riecke [12], [13] and published in German. A translation of Riecke [13] is provided as an appendix to Gordon and Whitehouse, 2022 [2]. In this paper Riecke presents the equations using CGS ESU dimensions for the variables. Then, using the method of successive approximation, he calculates the distribution of the electric field withing the gas between plane-parallel electrodes. However, there is no motivation for the form of the equations or of the implication of the solution other than the results of the calculations can be used to estimate the recombination coefficient of the gas.

In 1932 Karl K Darrow, a Physicist at the Bell Telephone Laboratories, published a book, entitled *Electrical Phenomena in Gases*, [17] where he derives the gas dynamic conduction equations from first principles, including terms for the electric field and diffusion. Darrow also makes important observations of the physical implications of these equations. For convenience, an extract of this derivation and of its importance is presented as an appendix to this paper. The primary conclusion is that terms involving gaseous ion recombination and diffusion result in a pair of non-linear second order differential equations involving the electric field within the gas. This results in the electrical conduction of the gas being non-ohmic so that there can be a current through the gas even though the voltage between the electrodes is zero, *i.e.*, a 'short circuit' current, or that there can be a potential difference or voltage between the electrodes even though there is no current flowing, *i.e.*, an 'open circuit' voltage. This non-ohmic conduction is one of the major characteristics of self-initiating and self-sustaining LEC performance.

Neglecting the contribution of the diffusion of ions is justified when the electric field is sufficiently great so that the drift of the ions due to the electric field is much greater than the contribution to the current density by the diffusion of the ions [14]. This is the case when using the conduction of electricity through the gas as a method to measure the ionization of the gas caused by external ionizing radiation and quantifying the amount of this external radiation. However, when analyzing the performance of a LEC, diffusion of the ions must be taken into consideration when estimating the power that a LEC can deliver to an external load, and thus the distribution of the electric field becomes important. As an alternative to the use of successive approximation Tate in 1966 [24] provides multiple estimates of the electric field within the gas for different gas dynamics that can be numerically computed. He finds that even with some simplifying assumptions that the differential equation for the electric field between parallel electrodes is a 4^{th}-order non-linear differential equation.

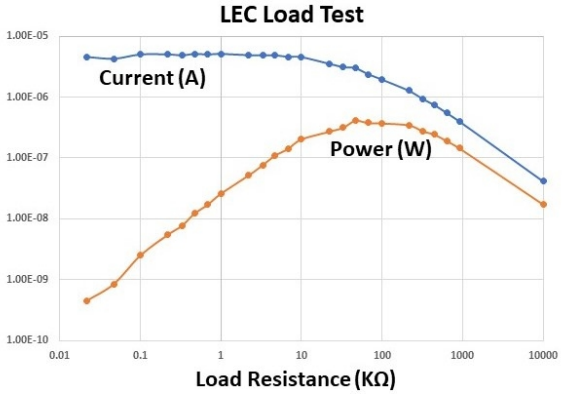

Figure 1. A typical plot of the current (A) and power (W) produced during a load test. As with most power supplies, the power peaks when the internal cell impedance matches the external load impedance

A standard way to characterize electrical power supplies is to measure open circuit voltage and short circuit current. In the case of the LEC, a 10 MΩ load resistance was used to measure the 'open circuit' voltage, and a 10 Ω load resistance to measure the 'short circuit' current. By measuring the voltage produced through intermediate resistance values, it is possible to calculate the current and power delivered to an external load as a function of resistance and temperature. Figure 1 is a typical plot of current and power as a function of load resistance for a given temperature.

Analysis of experimental results indicates that LEC performance is strongly dependent on the non-linear interactions between multiple parameters such as electrode preparation, electrode separation distance, cell temperature, and the physical properties of the gas [15], [16], [17], [18], [19]. For example, depending on the source and type of ionizing radiation, ionization is expected to increase as the number-density (fill-pressure) of the gas is increased. Thus, gas-ion dynamics is important. Ohmart [20] and RCA [21] report that the work functions of the electrodes also have a role in the performance of cells containing ionized gas even though the gas within the cell is ionized by an external source of ionizing radiation. The importance of the work function of the electrodes on the performance of a LEC is presented in Gordon and Whitehouse [2]. What is surprising is the important role that is played by the diffusion of the ions, *e.g.,* diffusion of positive ions to the positive electrode of the LEC cell. As shown in Fig. 2, electrons flow from the low work function electrode through the external load to the high work function electrode. However, to complete the circuit within the cell, more negative ions than positive ions must flow to the low work function, negative electrode, where they deposit an electron while more positive ions than negative ions must flow to the high work function, positive electrode, where they acquire an electron. Ion diffusion and gas dynamics contribute to this behavior. This is counter-intuitive since electrons normally flow to the electrode with a more positive charge, such as what happens in the electrical circuit that is external to the cell.

2. Increasing LEC Power

The big challenge with all direct energy conversion devices is the number of charge carriers that are required to produce useful power. One ampere of current requires approximately 6.24×10^{18} charge carriers per second. The number of Becquerels produced per second by one Curie of radiation which is 3.7×10^{10}. Even using unreasonably optimistic assumptions that each high energy particle emitted from a radioactive source can ionize 10^5 ions, and if all of the ions produced are collected by the electrodes before they recombine, it will still take more than 1000 Curies of radioactive material to produce 1 amp of current. One commercial atomic power source is advertised as producing

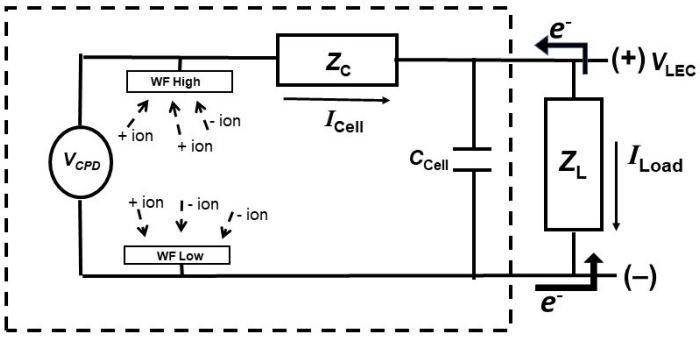

Figure 2. By convention, current flows from the positive to the negative electrode which means that electrons are flowing from the negative (low work function) electrode through the external load impedance Z_L to the positive (high work function) electrode. However, to complete the circuit, more negative ions than positive ions need to flow to the negative electrode while more positive ions than negative ions need to flow to the positive electrode within the cell. Ion diffusion and gas dynamics contributes to this behavior.

100 milliwatts of power from a 100 Ci tritium source [22]. To scale that up to produce 10 watts would require 10,000 Ci of tritium. This requirement has limited the application of direct energy conversion devices that rely on radioactive materials to produce ionized particles. On the other hand, unlike nuclear devices where the primary option is to increase the radioactivity, LECs do not require naturally radioactive materials and experimental results indicate that there are multiple opportunities to increase output power.

Based on experimental results and the equations derived by Darrow, [17] five interconnected/nonlinear focus areas, that may not be independent variables, have been identified that may increase LEC output by 6 to 9 orders of magnitudes include:

1. Improved metallurgy to increase the ionization rate to increase the gas ionization;
2. Optimize gas dynamics involving mobility, diffusivity, initial pressure, gas composition;
3. Improved LEC cell configurations such as electrode separation to increase gaseous ion harvesting efficiency;
4. Optimize temperature to increase the number of ions being produced, as well as their diffusion, leading to a corresponding increase in power output; and,
5. Increased electrode surface area.

2.1. Improved Metallurgy to Increase the Production of Ionizing Radiation

The lattice dynamics required to produce the ionizing radiation remains a subject of much discussion among LENR theorists. However, there is considerable evidence that ionizing radiation is being produced by an electrode that is codeposited with Pd or Fe that is occluded with hydrogen or deuterium. Extensive testing at the Bahaba Atomic Research Center in India by Dr. Srinivasan and others in the early 1990s showed that radiation would fog film, but even using very sensitive instruments, they were unsuccessful in detecting and identifying the type of radiation [23]. A LEC shows that the radiation being produced is sufficient to ionize a gas between two electrodes and that the ions thereby produced can be harvested to produce a voltage and current through a load. LEC experimentation suggests that the ionization is being produced by a few localized active sites. Better metallurgy to increase the number of active sites could increase the number of ions being produced, leading to increased LEC output. A target increase of the production of ionizing radiation could provide 1 to 2 orders of magnitude increase in power output.

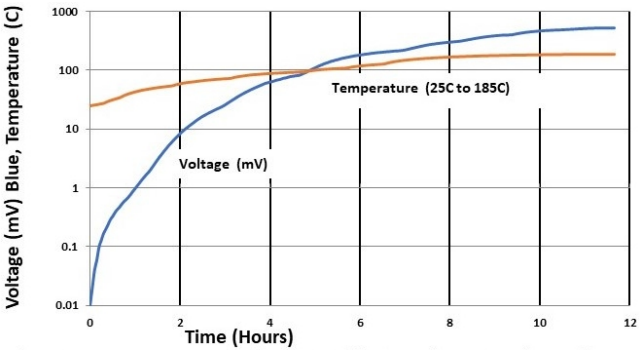

Figure 3. As Temperature increased from 25° C to 100° C, voltage increased approximately 4 orders of magnitude (Z128G22vi05 data set)

2.2. Increase Gaseous Ionization Production

Optimizing gas density (initial pressure) to ensure that the energy being emitted from the active material (Pd-H of Fe-H) will be exhausted producing ions is another way to increase the number of ions that are produced. Additionally, it is possible to use gas mixtures such as Penning gases that require fewer electron volts per ion pair produced. Optimization of gas ionization production could provide an improvement of 1 to 2 orders of magnitude.

2.3. Improved LEC Cell Configurations to Increase Gaseous Ion Harvesting Efficiency

Based on experiments where an external voltage is applied to produce an electric field that sweeps out the ions being produced before they can recombine, we estimate that in the absence of a strong electric field, the LEC is harvesting approximately 0.1% of the ions being produced with the majority of ions being recombined. Understanding the importance of electric field and diffusion on gas ion dynamics could be important to increase ion harvesting efficiency. The importance of the physical position and separation of the electrodes depends on both the type of ionizing agent or agents; as well as the distribution of the ions within the gas. For heavy particles, such as protons [25] and α-particles, [26] large electrode spacings may be appropriate while for light electrons [27] the electrodes may be closer together. Thus, it is important to determine the distribution of ions within the gas and the role that electrode shape and position have in LEC design. The authors believe that increasing the efficiency of ion harvesting can produce an improvement of 1 to 2 orders of magnitude in power output.

2.4. Optimize LEC Temperature Leading to Increase Power Output

Multiple experimental results and supporting analysis indicate that the number of ions being produced and harvested increases with temperature. As shown in Fig. 3, approximately 2 - 3 orders of magnitude increase occurred when the temperature was increased from approximately 22 °C to 80 °C and approximately 4 orders of magnitude increase when the temperature was 100 °C. This is encouraging in that even modest temperature increase will produce a significant increase in LEC output, and based on experimental results, it appears that a target of 2 – 3 orders of magnitude increase in power is reasonable with a higher temperature.

2.5. Increased Electrode Surface Area

Increasing the surface area of electrodes is the most obvious opportunity to increase LEC output. The experimental data has been normalized to power per square centimeter of electrode surface. Increasing from 1 square centimeter to

1 square meter increases the surface area by 4 orders of magnitude. In this regard, plane-parallel cell designs which will allow significant increases in surface area are being tested. Based on experimental results, a target of 3 to 4 orders of magnitude by increasing surface area is reasonable.

For each of the five focus areas, experiments and analysis are required to:

1. Identify the source and type of ionizing radiation emitted from the working electrode;
2. Identify the role that the counter electrode may play in ionizing the gas;
3. Identify gases and mixtures that optimize the production of ions; and,
4. Analyze the gas ion physics within the cell which is a 4^{th}-order nonlinear differential equation.

Supporting analysis of experimental LEC results will provide important information in LEC cell designs. Attempting to optimize a nonlinear process that involves several variables based on experimentally produced empirical information alone is a challenging problem.

3. Conclusion

Based on the experimental results and theoretical analysis, although there is much work to be done, and even though the focus areas for improvement may not all be independent, it appears that it might be possible to increase the LEC power output by the 6 to 9 orders of magnitude required to become a useful power source.

Appendix: Flow of Ions Under the Joint Influence of Fields and Concentration-Gradients

Quoting from Karl K. Darrow, Electrical Phenomena in Gases, Chapter V, (1932) 189–194

"In this section I will derive some general equations for the distribution and flow of ions through gases which are constantly being ionized by rays from without. These equations and the ways of verifying them were much considered, ten to thirty years ago; perhaps hereafter they will again be useful.

Consider a layer of gas between two infinite parallel plane electrodes a distance *L* apart; imagine that ions are being formed throughout its volume at a constant rate, *q* positive and *q* negative appearing per unit volume per unit time. Lay the axis of *x* perpendicular to the plates, with *x* increasing from anode to cathode. Consider the current-flow through a column of gas extending from unit area of the cathode to unit area directly opposite on the anode; the current this column will be the same as the current-density *i*. Everything will depend on *x* alone.

With too low a potential-difference between the electrodes and therefore too low a field strength, some of the ions will be lost by recombination (Chapter VIII) or by diffusing to the wrong electrode, positives wandering to the anode and negatives to the cathode. With too high a field strength primary ions will engender new ones (Chapter IX). If the density of the gas is not too high, there will be an intermediate range of field strengths, over which all the primary positives will be drawn the cathode and all primary negatives to the anode (Chapter IX). The current-density will then have its "saturation" value i_s:

$$is = qLe \tag{60}$$

A relation which gives a way of measuring *q*.

Denote by n_1 the number of positive ions per unit volume, by μ_1 their mobility, by D_1 their coefficient of diffusion, by *E* the field strength. The field causes a drift of ions over the cross-section, amounting to $n_1\mu_1E$ of these particles per second.[10] But this is not the whole of the drift, unless the concentration is everywhere the same, which we should not assume to be the case even if the ionizing rays are everywhere equally strong. If n_1 varies with *x* there is a concentration-gradient dn_1/dx, and the drift is the sum of $n_1\mu_1E$ and an extra term – $D_1(dn_1/_{dx})$. This multiplied by *e* is the contribution of the positive ions to the current-density at *x*. Denoting by n_2, μ_2 and D_2 the concentration,

mobility, and coefficient of diffusion of the negative ions, we have for their contribution the product of *e* into the sum[11] of n_2 $\mu_2 E$ and + $D_2(dn_2/dx)$. Adding we obtain for the current-density the formula,

$$i = e[(n_1\mu_1 + n_2\mu_2)E + (D_2 dn_2/dx - D_1 dn_1/dx)] \tag{61}$$

and since it must be independent of x (otherwise there would be piling up or dwindling away of charge in various regions of the gas, contrarily to our tacit assumption that the state of affairs is unchanging) the right-hand member like the left-hand member is equal to a constant.

This differential equation, however, does not help us much by itself, for it involves the two functions n_1 and n_2, not to speak of *E* which (as we shall later see) is very likely to vary with *x*. We require a pair of equations for n_1 and n_2; and such we can obtain by invoking what is known not only about mobility and diffusion, but about generation and recombination of ions. Consider any slice of the column, between planes at *x* and *x* + *dx*. In this slice, *qdx* ions of either sign are being generated per second, and $\alpha n_1 n_2 dx$ of either sign are vanishing per second by recombination.[12] In addition, there is the possibility that more may be drifting through one side of the slice than through the other. Let us take account of the positives first. Through the side *x*, into the slice their drift per second the number ($n_1\mu_1 E$ – Ddn_1/dx) of them, all the variables in the parenthesis being evaluated at *x*. Through the side *x* + *dx*, *out of* the slice, their drift per second a number given by the same expression, except that now all the variables are to be evaluated at *x* + *dx*; we have:

$$(n_1\mu_1 E - Ddn_1/dx)x + dx = (n_1\mu 1_E - D_1 dn_1/dx)x + (\mu_1 d(n_1 E)/dx - D_1 d^2 n_1/dx^2)dx \tag{62}$$

The difference between these is the net rate at which the positive ions in the slice tend to increase because of drift. Now adding together the rate of generation of ions in *dx*, and the rate of disappearance through recombination, and the rate of increase because of drift, each with its appropriate sign according as it is gain or is loss, we have for the rate of change of the number of positives in the slice *dx*,

$$d(n_1 dx)/dx = qdx - an_1 n_2 dx - (\mu_1 d(n_1 E)/dx - D_1 d^2 n_1/dx^2)dx \tag{63}$$

But in the steady state, n_1 must be unchanging; so, dividing out *dx*, we get a differential equation involving n_1 and n_2 and space-derivatives of n_1; there is a corresponding equation to be obtained by thinking in the same way about negative ions, and writing both of them down together, we have:

$$\begin{aligned} q - an_1 n_2 + D_1 d^2 n_1/dx_2 - \mu_1 d(n_1 E)/dx = 0 \\ q - an_1 n_2 + D_2 d^2 n_2/dx_2 + \mu_2 d(n_2 E)/dx = 0 \end{aligned} \tag{64}$$

I pause to point out that equation (61) may be derived from these by subtracting one from the other, and integrating once with respect to *x*.

It now seems as if everything in the discharge—the current-strength, the distribution of the ions of both signs, and so forth—is determinate once we know the rate of generation of ions, and the values of the coefficients α, μ_1, μ_2, D_1 and D_2, and the proper boundary-conditions. But there is still something new to be taken into account: the variation of field-strength *E* with *x*. Since we have been assuming that the gas is enclosed between two parallel plates, it seems natural to put E constant and equal to the quotient *V/L* of the potential-difference between the plates by the distance between them. Not so: the field strength cannot be constant in any region where the density of charge of one sign differs from that of charge of the other sign; for then there is a net density of charge different from zero, there is a space-charge which by Poisson's formula of electrostatics must entail a value of *dE/dx* different from zero. In this special case, where the net density of charge is $(n_1 - n_2)e$, Poisson's formula yields the equation:

$$dE/dx = -4\pi(n_1 - n_2)e \tag{65}$$

so that we have a family of three differential equations involving the three functions n_1, n_2, E of the independent variable x. In dealing with them we must replace the too-simple assumption that E is equal to the quotient V/L by the general statement that the integral of $E(x)$, taken across the gas from $x = 0$ to $x = L$ is equal to V.

I do not, however, wish to enter yet into the questions involving space-charge; a later chapter is to be devoted to that subject. Space-charge would play no part, of course, if n_1 and n_2 were equal; but this is a condition which the difference in mobility of the two kinds of ions makes difficult to approach—one easily sees that if carriers of both signs are generated at an equal rate, and the negatives drift faster than the positives, there will be fewer negatives than positives at any moment between the plates. However, it is interesting to simplify the equations in the way which would be permissible, were n_1 and n_2 sufficiently nearly the same. Recombining equations (64) into equation (61), making n_1 and n_2 equal and denoting each of them by n, we get:

$$i/e = n(\mu_1 + \mu_2)E + (D_2 - D_1)dn/dx \tag{66}$$

an equation easy to integrate when the mobilities and diffusion-coefficients are assumed independent of x. What is peculiarly interesting is that E and i do not necessarily vanish together. Let us put i equal to zero: then integrating (66) under the stated assumptions, we get:

$$\log n = (\mu_1 + \mu_2)Ex/(D_2 - D_1) + const. \tag{67}$$

Denoting by n_0 and n_L the values of n at the two plates, $x = 0$ and $x = L$ respectively: we get:

$$\log n_L/n_0 = (\mu_1 + \mu_2)EL/(D_2 - D_1) = (\mu_1 + \mu_2)V/(D_2 - D_1) \tag{68}$$

Recalling equation (59) [$D/\mu_e = 2U/3$] of page 188, and denoting by U_1 and U_2 the values *in equivalent volts* of the mean kinetic energy of the positives and the negatives respectively, and expressing V *in volts* (not E. S. U.), we find:

$$\log n_L/n_0 = (3/2)(\mu_1 + \mu_2)V/(U_1\mu_1 - U_2\mu_2) \tag{69}$$

These equations are to be interpreted as follows. Suppose that ions of the two signs are spread identically through a gas between two walls—by "identically" I mean that everywhere the concentrations of the two kinds are equal, though their common value varies from place to place—and that the state of affairs is stationary. Then there must be ionizing rays acting continually on the gas, and also there must be a potential-difference between the walls. For if there were no field, the negatives would diffuse along the concentration-gradient more rapidly than the positives; there would be a net current; this would result in a depletion of negatives, and an excess of positive charge would arise in the gas, in contradiction with the assumption. But suppose there is a P.D. between the walls, in such a sense as to oppose the negatives and pull the positives forward as they stream together down the gradient. A value for this potential-difference can be found, such that the field strength will retard the negatives and encourage the positives just sufficiently to annul the net current aforesaid; and that is the value determined by equation (69).

This is another illustration of the principle which we have met already and shall meet again in the chapter on diffusion. Uneven distribution of ions act like an electric field in that it tends to cause an ion-flux, a current of electricity. In other and more conventional words, a non-uniform distribution of ions entails an "electromotive force." Or, in morae conventional terms, to annul the current a real potential-difference must be applied to compensate the electromotive force.

Equation (69) provides the formula for this compensatory P.D.—we might as well say the formula for the electromotive force itself—in a special case: that in which the densities of charge of the two signs are everywhere equal. Various "test" experiments have been made in conditions where this last was not *a priori* certain: as for instance one by Wood, de Long and Compton,[13] who set up two parallel plates bounding a stratum of gas, and applied ionizing rays (X-rays) to a thin sheet of the gas near one of the plates. They measured the values n_0 and n_L of the concentrations

near each of the plates (by applying a relatively strong field for just the time required to sweep into one of the plates all the ions of one sign within a fraction of a millimetre thereof) and the voltage which had to be applied across the gas in order to bring to zero the current flowing while the rays were shining. The ratios of n_0 to n_L were of the order of four or five to one: in these experiments, the calculated values of *V* were .0050, .0053 and .0063, while the corresponding measured values were .0042, .0034 and .0067.

[10]It is assumed that the variations of *E* from place to place are so gradual, that at each point the drift-speed of the ions has sensibly the terminal value corresponding to the there-prevailing field strength.

[11]Here, as in so many other cases, it is simpler and safer to decide from "physical considerations" what the signs of the various terms should be, than to keep in mind the proper signs of all the factors. If *E* is positive, the positive ions on the one hand and the negative ions on the other are pushed each in the proper direction (the positives towards the cathode, the negatives toward the anode) to make a positive contribution to the current if dn_1/dx is positive, the positives tend to diffuse in the wrong direction (away from the cathode); if dn_2/dx is positive, the negatives tend to diffuse in the right direction (towards the anode).

[12]See Chapter VIII.

[13]E. B. Wood, O. A. de Long & K. T. Compton, **PM** (6) **32**, 499-504 (1916). Earlier work of this kind had been done by J. Zeleny and W.H. Jenkinson."

Comments: The reader should note that the unit system used for *expressing* the equations is presented using CGS ESU. Also, in equations 67, 68, and 69, log should be read as the natural logarithm, ln.

Acknowledgments

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