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Research Article

Progress in Understanding and Scaling Up the Lattice Energy Converter (LEC)

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Abstract

The Lattice Energy Converter (LEC) is an electrophysical gaseous electronic device (GED) where hydrogen occluded hydrogen-host-material (HHM) in fluidic contact with the gas results in the gas becoming spontaneously and continuously ionized without requiring the use of naturally radioactive materials. The physical process and nature of the ionization is currently unknown since any possible ionizing radiation is difficult to d etect. The ionized gas is an electrolyte in the sense that it contains both positive and negative mobile ions. Thus, when the gaseous electrolyte is in fluidic contact with the electrodes and an external potential difference is applied between the electrodes, the device operates in a manner similar to an ionization chamber and the density of the gaseous ions can be estimated. However, when the ionized gas is in fluidic contact with separated electrodes that have different work functions, a LEC cell results. A LEC cell self-initiates and self-sustains the production of an 'open-circuit' contact potential difference (CPD) voltage between its electrodes that can be measured. Upon connecting a load impedance to the LEC's electrodes, a current will flow thus c harging a c apacitive i mpedance o r d elivering e lectrical p ower t o a r esistive i mpedance. Furthermore, the CPD phenomenon may be used with materials other than gases, such as auto-ionizing or self-ionizing liquids, gels, or even solid-state materials. When these non-gaseous materials have mobile ions and thus behave as an electrolyte, they can be used to implement another type of CPD direct energy conversion device. Both CPD gaseous and non-gaseous devices and combinations thereof form a new class of Electrophysical Direct Energy Converter (EDEC) devices.
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Keywords: Direct energy conversion, Electricity generation, Ionizing radiation.

1. Introduction

The electrophysical phenomenon of spontaneous and continuous production of electrical output by gaseous electronic device (GED) Lattice Energy Converters (LECs) has been presented at multiple international conferences [1]–[5] related to Condensed Matter Nuclear Science (CMNS) and has been published in peer-reviewed journals [6]–[8]. These surprising results are repeatable and have been independently replicated by other researchers [9]–[13]. The physics

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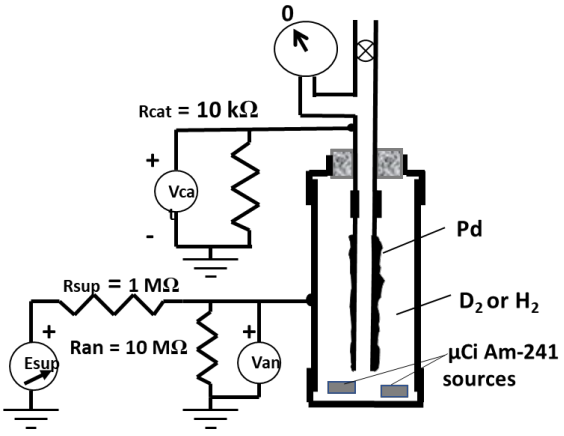


Figure 1. LEC cell constructed to conduct high-temperature gas electrolysis that included up to 6 μCi Am-241 sources to ionize the gas. A variable external voltage up to 1000 volts could be supplied through a resistor circuit and the current was calculated using Ohm's Law.

and mathematics supporting this capability has evolved starting with A. Volta's research on the contact electrification of dissimilar metals [14] more than 225 years ago and with subsequent contributions by multiple scientists up to the present time that are presented in the appendix. Although a complete understanding of the underlying physical processes is lacking, experimental electrical repeatability and independent LEC device replications confirm the surprising LEC phenomenon. The author's current focus is to scale up the gaseous CPD-LEC device power output. One possible way to increase the performance of CPD devices is to take advantage of the auto-ionization or self-ionization properties of many liquid, gel, or solid-state electrolytes in combination with the LEC phenomenon including the possibility of combining non-gaseous auto-ionizing electrolyte with the active hydrogen-host-material (HHM) thereby producing a new category of CPD Electrophysical Direct Energy Converter (EDEC) [15] devices, involving electrophysical phenomena.

2. Background

Surprising results were observed in 2013 while conducting experiments to see if it was possible to perform high temperature electrolysis of a hydrogen or deuterium gas electrolyte to load atomic hydrogen or deuterium into palladium (Pd) hydrogen-host-material (HHM) electrodeposited on an electrode [2], [3]. It is well known that for an electrical current to pass through a gas, ions must be present in the gas [16]. For this reason, as shown in Fig. 1, up to six 1-microcurie sources of Am-241 radiation ($\sim$10% gamma-ray and $\sim$90% alpha-particle) were placed in a closed cell to ionize the gas between two concentric electrodes with the inner electrode electroplated with Pd. The experiment was a success. However, after analysis, it was realized that the current that was conducted was several orders of magnitude greater than expected based on the number of ions produced by the Am-241. The initial reaction was disbelief, and that possibly other phenomena such as water vapor or experimental error were involved. However, after multiple additional experiments, including removing the Am-241 sources and operating the cell at minus 55 °C, it was clear that the electrode with the hydrogen occluded co-deposited Pd HHM was ionizing the gas and thus the LEC phenomenon was discovered. 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."

The fact that the electrophysical CPD phenomenon [17] so essential to the implementation of a LEC device, is easy to produce and replicate leads one to wonder why it hadn't been previously discovered [18]. In contrast with most GEDs [19]–[20], a LEC cell is basically a diffusion driven device based on an electrophysical CPD phenomenon potentially in concert with Lattice Enabled Nuclear Reactions (LENR) or some other form of a non-nuclear phenomenon that ionizes the gas. A review of the literature going back more than 225 years identifies several missed opportunities to discover the LEC phenomenon and to develop LEC devices. While conducting contact electrification and electrophysical CPD electric 'pile' studies, A Volta accidentally discovered that using zinc (Zn) instead of tin (Sn) as one of his electrodes produced a better electric 'pile.' This electrochemical oxidation-reduction reaction became the forerunner of today's chemical batteries. This improved easier to measure electrochemical performance diverted Volta's attention away from the electrophysical CPD reactions of the EDEC.

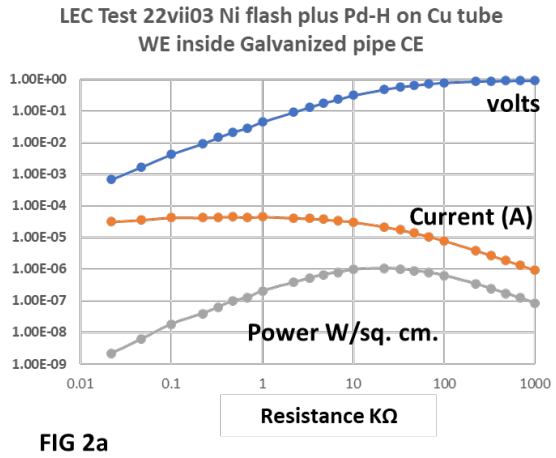
JJ Thomson [21] and others used external sources of ionizing radiation with an applied electric field to transport the ions in their studies of the conduction of electricity through gases. Throughout most of the intervening years, diffusion has been neglected because, in the presence of an electric field, the contribution of diffusion is insignificant [22]–[23]. In addition, many of the processes involving diffusion in a LEC device are surprising, *e.g.* "... positive ions diffusing against the electric field to the higher work function electrode with a positive potential difference." [28]

Although some of the physical and electrical phenomena involved are not fully understood, such as the source of any ionizing radiation that might be involved, multiple experimental results as well as multiple replications confirm the existence of the LEC phenomena. The LEC is very simple in appearance but extremely complex to analyze. Even when simplifying assumptions are made, the gas-ion dynamics that are required to determine the electric field and the distribution of the ions in the gas, results in a 4^{th}-order non-linear differential equation without an analytic solution that has to be solved numerically [23]. Additionally, some of the simplifying assumptions eliminate terms that may be important in LEC operation. A paper published by Chabod in 2008 [24] proposes an analytic solution to the non-linear differential equations when both diffusion and space charge are neglected. It is interesting to note that in researching the literature to understand the LEC, several articles related to diffusion and the conduction of electricity through gases are published in the journal *Physics in Medicine & Biology (Phys Med Biol)*. Another important reference is Jean-Paul Biberian's book [25] titled "*Fusion in All Its Forms: Cold Fusion, ITER, Alchemy, Biological Transmutations.*" Understanding the LEC and other CPD EDEC devices involves multiple disciplines and requires an open mind to learn what the experiments are revealing.

3. Progress up to ICCF-25, August 2023

Figure 2a illustrates experimental results that were presented at ICCF-24 in July 2022 [4], that produced a maximum cell power output of approximately 300 nanowatts and a cell current of 4 microamps per square centimeter. Figure 2b illustrates experimental results that were presented at ICCF-25 in August 2023 [5], that produced a maximum cell output power of 30 microwatts and a cell current of 138 microamps per square centimeter which is approximately 2 orders of magnitude increase from ICCF-24. These improvements resulted from multiple experimental tests with multiple LEC cell configurations. Scaling up the ICCF-25 cell results by an additional 5 orders of magnitude would produce 3 watts, and 8 orders of magnitude would produce 3 kilowatts of 'green' electrical power. Multiple opportunities are available to achieve this goal, including increasing the area of the cell's electrodes, increasing the amount of active-HHM per unit electrode area, increasing the number of cells, improved active-HHM metallurgy, improved electrolytes between the electrodes, and different LEC cell configurations.

Describing the electrical circuit of a LEC cell: Figure 3 illustrates a combined phenomenological, physical, and electrical representation of the behavior of a CPD-LEC cell. As shown, electrons travel in the external circuit from the cell's low work function (low potential) electrode to the cell's high work function (high potential) electrode in response to an equilibration of the Fermi levels of the two electrodes [26]. However, in practice the electrical connections to the



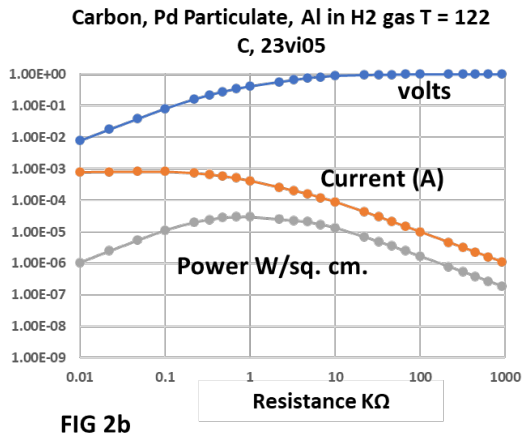


Figure 2a and 2b. Illustrate test results using different LEC cell configurations. Fig. 2a uses codeposited palladium and Fig. 2b used Palladium particulate as the working electrodes.

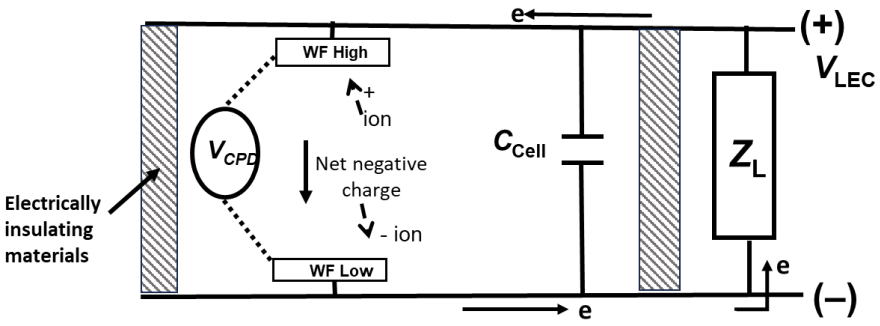


Figure 3. This phenomenological, physical, and electrical representation of the behavior of a LEC Contact Potential Difference device illustrates the flow of electrons from the low work function electrode, through the external load to the high work function electrode and complete the circuit back to the low work function electrode through the gas. This figure also illustrates the electrically insulating materials separating the electrodes.

low and high work function electrodes are at the ends of the electrodes. This results in a potential gradient in the low and high work function electrodes so that when the load resistance is low the voltage, and thus the electric field, near the connection with the load resistance is low while away from the connection with the load impedance the voltage and thus the electric field is greater. This results in a complicated spatial ion dynamic within the gas.

The effect of the complicated spatial ion dynamic is that a LEC cell—as shown in Fig. 2—experimentally behaves as a current source for low values of load resistance even though in the ideal case—described by I Langmuir [17]—there is an electric field between the electrodes due to the CPD produced by the difference in work function of the electrodes when the load resistance is low. The low resistance load impedance connection of the electrodes and the corresponding equilibration of their Fermi levels results in a buildup of negative charges in the high work function electrode and a

diminution of negative charges in the low work function electrode. For this flow of electrons to continue and thus to complete the circuit and cause a continuous current to flow, negative charge must be transferred from the high work function electrode to the low work function electrode by ions in the cell's electrolyte. This is counterintuitive since for an ionization chamber mode LEC (IC-LEC), when an external voltage is applied to a LEC cell, positive ions are attracted to the low potential electrode, and negative ions are attracted to the high potential electrode by the electric field.

However, for a CPD-LEC at low cell voltage, where the density of positive and negative ions are almost equal, some positive ions will actually diffuse against the electric field to the high work function (positive potential) electrode and become neutralized by removing excess electrons from the high work function electrode. This then allows more electrons to flow from the low work function electrode through an external load impedance to the high work function electrode because of the equilibration of the Fermi levels of the electrodes [26]. In essence, the high work function material will gain more electrons than its natural state, and one way to get rid of them is to transfer them to positive ions in the electrolyte.

A similar process takes place at the low work function electrode where negative ions replace electrons lost by charge equilibration. Note, that if the high work function electrode were LENR active and emit electrons as some current theories predict [27], the positive ions would not have to diffuse against the electric field all the way to the positive electrode and LEC performance would be enhanced.

As shown in Fig. 2a and 2b, when the load resistance (Z_L) is greatest, the voltage measured across the load is essentially the difference in their work functions and the electric field is low. Therefore, they diffuse with the ion concentration gradients, or simply recombine without moving within the gas [28]. As the load resistance is reduced, the LEC cell's electric field reappears in the gas space so diffusion against the electric field gradient increases and limits the production of cell current. Experimentally, peak cell power output occurs when the effects of the electric field and diffusion are approximately equal, *i.e.*, for plane-parallel electrodes, when the average ion drift-lifetime:

$$\tau d = d/\mu E_{\mathrm{cell}} \approx d^2/\mu V_{\mathrm{cell}}$$

equals the average ion diffusion-lifetime:

$$\tau D \approx d^2/\pi^2 D$$

or their ratio is unity, such that:

$$\tau_d/\tau_D \approx \pi^2 k_{\mathrm{eV}} T/V_{\mathrm{cell}} = 1$$

where by the Einstein relationship the diffusion coefficient is $D = \mu k_{\mathrm{eV}} T$ and μ is ion mobility in distance squared per volt-second, k_{eV} is Boltzmann's constant in electron volts per kelvin, T is the ion temperature in kelvin, d is the electrode separation distance, E_{cell} is the electric field in the gas measured in volts per unit distance, and V_{cell} is the LEC cell's voltage assuming space-charge can be neglected:

$$V_{\mathrm{cell}} = -\int_0^d E_{\mathrm{cell}} dx$$

Since $k_{\mathrm{eV}} T$ is approximately 25 millivolts at room temperature, maximum room temperature LEC power occurs at a LEC cell voltage of approximately 250 millivolts and increases as cell temperature increases. The positive effect of the temperature may also be due to the increased LENR activity.

It should be recognized that at experimentally measured LEC current densities, there is significant space-charge in the gaseous electrolyte, and ion-ion recombination occurs throughout this process. Since the time required to collect the ions decreases as the ion mobility increases, and decreases with electrode separation distance, LEC cell designs that consider these properties can be used to increase LEC cell performance. The electrical current calculated at low

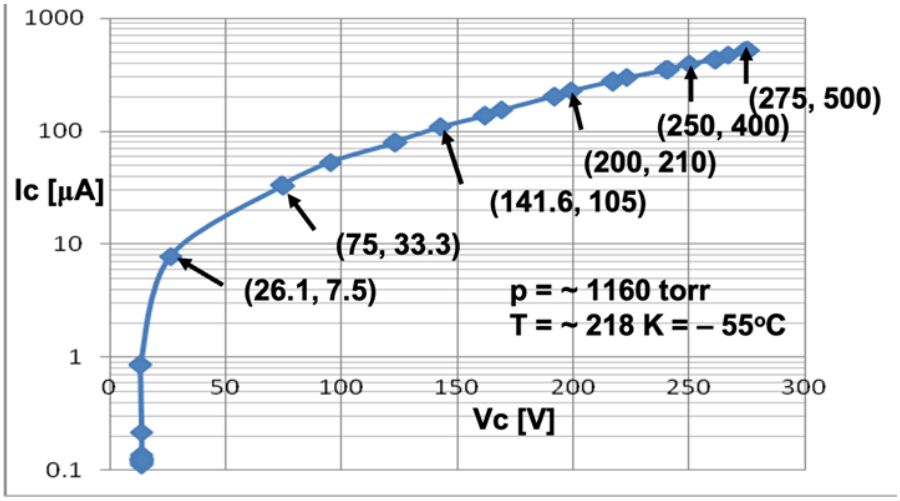


Figure 4a. Semilog plot of cell current (A) vs cell voltage

resistance levels was approximately 1 milliamp which is 6.24×1015 single-charge carriers recovered per second. According to JJ Thomson's steady-state ion density calculation [29], $n_{\rm ss} = (q/\alpha)^{1/2}$, for a uniform ionization rate, q, that includes recombination, $\alpha n_{\rm ss}^2$, but without diffusion, the total number of ions produced in the gas can be several orders of magnitude more than those that are collected due to recombination of the ions.

4. Describing the Physics and Mathematics of LEC Device Conduction

Figure 4 shows the ionization chamber (IC) mode cell conduction, IC-LEC, behavior for the original Pd-D cell device discovery cell without any Am-241 sources. The cell was configured as shown in Fig. 1. Starting from a high voltage when the anode voltage, $V_{\rm an}$, was reduced the cathode voltage, $V_{\rm cat}$, also decreased and thus the cell current flowing through $R_{\rm cat}$ decreased. However, at a critical cell voltage, where the impressed electric field no longer dominates, diffusion and the work function contact potential difference (CPD) between the electrodes becomes important and the cell current sharply decreased. Thus, a LEC cell's spontaneous conduction is counterintuitive to the conduction of an ionization chamber like device with an impressed voltage, and requires that the differential equations describing the conduction of electricity in a gas including diffusion be considered [23], [28], [30]. Upon verifying that this non-ohmic behavior was a real phenomenon, due to the cell spontaneously generating its own current and not an instrumentation artifact, LEC device phenomenon was discovered. In addition to operation as a IC-LEC, this 'discovery' cell is still capable of generating a CPD-LEC current some 8 years later although it has had additional deuterium gas added a couple of times.

The Lattice Energy Converter (LEC) is a novel invention with the potential to dramatically change the worldwide energy posture without producing hazardous waste of greenhouse gas.

Figure 4 illustrates the surprising non-ohmic behavior as the external applied voltage is reduced to the point that diffusion terms become important due to electrophysical contact potential difference effects. Fig. 4a shows log of the measured cell current as a function of cell voltage. Fig. 4b shows the cube-root of the measured cell current as a function of cell voltage. By inspection, the current versus voltage is non-ohmic since the current is not zero when the Red extrapolated voltage is zero. This is shown in the following equation for the number of ions, *i/e* since when the

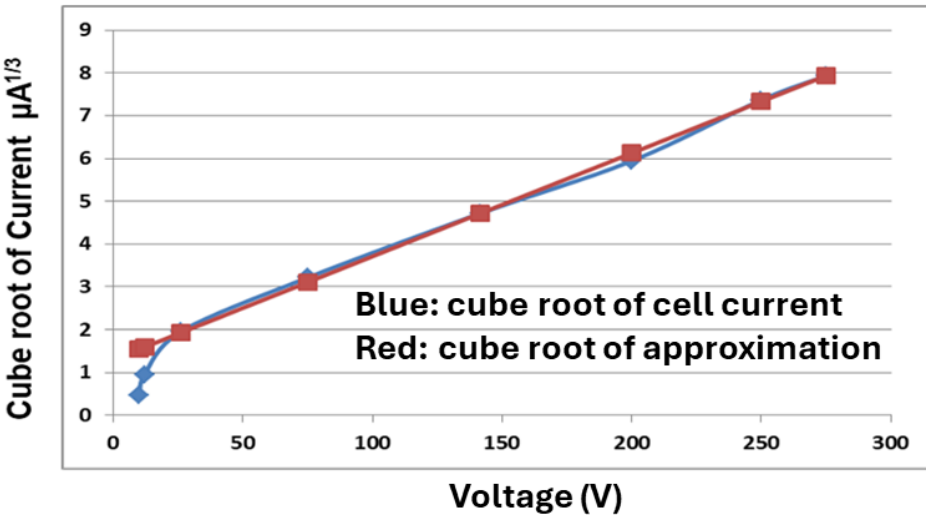


Figure 4b. Plots of the cube root of the current $\mu A^{(1/3)}$ vs cell voltage and polynomial approximation

electric field drift term goes to zero the diffusion term is not zero when $D_2 - D_1 \neq 0$ and the current density does not go to zero:

$$I_c^{1/3} = mV_c + I_c^{1/3}(0)$$

where $m = 0.0241\mu A^{1/3}/V$ and $I_c^{1/3}(0) = 1.3\mu A^{1/3}$. Both Fig. 4a and 4b show that diffusion becomes dominant when the cell voltage approaches zero.

The spatial 'charge-conservation equations' for plane-parallel electrodes, and 1-dimensional gas dynamics, were originally published by Eduard Riecke [30] but are derived and rewritten in modern notation by Karl K Darrow [28]. In addition to Poisson's equation for the divergence of the electric field, *dE/dx*, in the gas due to the spatial distribution of charge in the gas

$$dE/dx = 4\pi e(n_1 - n_2) \qquad dE/dx = e(n_1 - n_2)/\varepsilon$$
$$\text{[CGS\_ESU]} \qquad \text{[SI or CGSA]}$$

the charge conservation equations for plane-parallel are

$$q - \alpha n_1 n_2 + D_1 d^2 n_1/dx^2 - \mu_1 d(En_1)/dx = 0$$
$$q - \alpha n_1 n_2 + D_2 d^2 n_2/dx^2 + \mu_2 d(En_2)/dx = 0$$

where n_1 and n_2 are the positive and negative ion densities in ions per unit volume respectively, *e* is the unit electric charge in the appropriate unit system, $\varepsilon = \varepsilon_r \varepsilon_0$ is the permittivity of the gas, q is the ionization rate in ions per unit volume per second, α is the ion-ion recombination coefficient in unit volumes per second, $D1$ and $D2$ are the positive and negative ion diffusion coefficients in unit distance squared per second, d^2n_1/dx^2 and d^2n_2/dx^2 are the 2nd-derivatives of the positive and negative ion densities, μ_1 and μ_2 are the mobilities in unit distance per unit electric field per second of the positive and negative ions, and E is the electric field strength in voltage per unit distance. Note that in CGSA and SI unit systems, tabulated ion mobilities are in distance squared per volt per second. Therefore,

when using the CGS-ESU system, tabulated ion mobilities should be multiplied by approximately 299.79 "since unit electrostatic force [in CGS-ESU] is 300 volts per centimetre" [31].

According to Darrow, the 'current-density' equation can be derived from the charge-conservation equations "by subtracting one from the other, and integrating once with respect to x.":

$$i/e = (\mu_1 n_1 + \mu_2 n_2)E + (D_2 dn_2/dx - D_1 dn_1/dx)$$
$$\text{[ions]} \qquad \text{[drift]} \qquad \text{[diffusion]}$$

where *i/e* is the number of single charges recovered per second per unit area and is a function of both the electric field E, and the diffusion coefficients, D_1 and D_2, of the positive, n_1, and negative, n_2, ion densities per unit volume. Notice that if $E = 0$, the diffusion terms still exist, and if the diffusion coefficients $D_1 = D_2 = 0$, the electric field terms still exist. Darrow makes the observation that these equations describe a non-ohmic behavior since the electric field, E, or voltage ($V = -\int E(x)dx$) and current density, i, or current ($I = \int i(S)dS$) **"do not necessarily vanish" together**. As was shown in Fig. 4, this behavior has been observed in IC-LEC tests where an applied external voltage was reduced in steps while measuring the current between the electrodes and the cell became a CPD LEC.

It is important to note that the above current density equation needs to be reinterpreted for a spontaneously conducting CPD-LEC device. The number of charges per second per unit area, *i/e*, is negative, not positive, then the diffusion term on the right-hand-side of the equation should be reinterpreted to account for the counterintuitive diffusion of ions against their concentration gradients. Darrow explains this behavior in the following way:

> "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 toward 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 (toward the anode)."

Also, it is important to note that the two terms on the right-hand side of the 'current-density equation,' *i.e.*, drift and diffusion, have opposite effects on the migration of the ions and thus the current-density performance of a LEC cell. Increasing the electric field, *E*, causes more positive ions to drift to the low work function electrode and negative ions to drift to the high work function electrode, thus decreasing cell current output since completing the electrical circuit requires that the ions are "drawn" to the opposite electrodes as was shown by I Langmuir [17]. Simply stated, in a CPD-LEC cell, the electric field induced drift and diffusion work against each other. However, even though both drift and diffusion are present, as shown in Figs. 2a and 2b, a sustained current and voltage through an external load impedance is produced.

From the charge-conservation and current-density equations it can be seen that there are several opportunities to scale up a CPD-LEC cell's output power: by increased cell current density, *i*, which can be achieved by better metallurgy to increase the ionization, *q*, per unit volume per unit time; by different gas mixtures or electrolytes, *e.g.*, a Penning gas with a lower W-value of energy per ion-electron pair production; and, by decreasing the ion-ion recombination loss, $\alpha n_1 n_2$, through better cell design such as choosing an optimum electrode separation distance. Additional improvement in LEC cell power output can be achieved by increasing the ion temperature, *T*, and by using solid-state, gel, or fluidic electrolytes that include active HHM particulate materials.

5. Experimental Testing of LEC and CPD Devices

Tests using thorium dioxide, decorative sand, and monazite sand between the electrodes: As reported in *The Electrician*, [32] J. B. Kramer, in his presidential address before the Scientific Society of the Birmingham and Midland Institute, described experiments where he used radioactive material in air between two electrodes of different materials. In one experiment with carbon and zinc electrodes,

> "it appears that if a thick layer of monazite sand or r.a. ilmenite or other similar radio-active substance is spread over the surface of the carbon, the zinc may be laid direct on the top, and a steady deflection is still obtained on the electrometer. With such a couple the e.m.f. is approximately 1 V and the current obtainable with a small area cell was almost 3 by 10^{-4} A"

These are very interesting results, but other than the report in *The Electrician*, there is no further mention of these experiments. Bob Greenyer offered to send the authors some monazite sand to allow replication of Kramer's reported results. In addition to testing the monazite sand, some 99.9 % thorium dioxide powder was tested. Thorium is the radioactive component in monazite sand. As an additional material, some decorative sand was also tested. All three experiments produced similar conduction results when the different materials were initially placed between and in contact with electrodes of carbon and zinc. However, when the temperature was increased to above 100 °C, the voltage and current went below instrumentation sensitivity for all three materials. Furthermore, the amount of current that would be expected based on the published radioactivity of monazite beach sand, and even the voltage and current produced by the ThO_2 was below the detection sensitivity of the instrumentation available. These test results suggest that the voltage and current that Kramer observed and the voltage and current that the authors observed before heating the cells up to over 100 °C was the result of adsorbed moisture on the surface of the materials. Kramer may have come to the same conclusion because the anonymous report in *The Electrician* is the only reference to these tests.

In both the test by Kramer and those by Volta, zinc was used as one of the electrodes which will react with hydroxyl ions, $(OH)^-$, in moisture to form $Zn(OH)_2$ plus the release of 2 electrons . The presence of any moisture can produce mobile ions that will discharge the CPD [33]. This is a subtle electrophysical effect which is why testing at temperatures above 100 °C is important with experimental LEC cells. The adsorbed water effect will decrease with temperature while the CPD-LEC effect usually increases with temperature.

Testing LEC cell materials as a function of temperature: Several electrically insulating materials have been used in LEC cells to separate the working electrode from the counter electrode. While they all had 'infinite' electrical resistance at room temperature, these materials had not been characterized at temperatures up to 200 °C. As shown in Fig. 3, if the resistivity of these materials decreased at high temperatures, an alternate/parallel path would exist for current to flow between the electrodes, thereby decreasing the measured voltage and calculated current through the external load impedance (Z_L). For this reason, tests were conducted to determine if the resistance of the insulating materials was changing as a function of temperature. Nylon pipe bushings are particularly bad since they change resistance when hot air is blown on them. In general, during testing, the high temperature epoxies maintained very high resistance below approximately 110 °C. However, above that temperature, the high temperature epoxies developed mobile ions and began to act like an electrolyte. While these changes in resistance/conductivity might have corrupted some of the high-temperature data previously reported, they would have had minimal effect on test results below 110 °C. The materials with very little measurable change at high temperatures were PTFE and silicone rubber.

Tests using liquids, gels, and epoxy electrolytes: The realization that materials containing mobile ions could replace the gas between the electrodes opens the possibility that there might be alternative electrolyte materials than gas. Langmuir [17] describes contact potential difference designs where he states:

> "If we maintain the gas in an ionized condition, current will continue to flow. This current represents a definite amount of energy per second, equal to the product of the current by the contact potential. ... It is thus clear that the energy of the current is supplied originally by the ionizing agent."

Although Langmuir only discusses ionized gas, he doesn't preclude other sources of mobile ions. The possibility of using materials that naturally contain mobile ions or materials that would produce mobile ions at lower energy than the approximately 35 eV per ion pair needed to ionize hydrogen gas could be important.

Multiple tests were conducted using CPD-LEC devices where the gas was replaced with a class of solids such as high temperatury epoxy, gel, or fluid electrolytes comprised of amphiprotic substances and materials that self-ionize and contain mobile ions, have been shown by the authors to self-initiate and self-sustain the production of a current and voltage when in contact with separated electrodes of different work functions that generate a contact potential difference. Based on experimental results, the ion dynamics of these solids, gel, or fluid electrolytes appear to be governed by similar mathematics as gaseous LEC ion dynamics. When active HHM materials, including particulates, are incorporated within the solids, gel, or fluid electrolytes, cell output power has been found to increase over cells without the active HHM material. Both types of devices are based on the CPD phenomenon, and these improvements suggest a broad category of CPD Electrolytic Direct Energy Conversion (EDEC) devices. The combination of self-ionizing electrolytes and active HHM material provides another opportunity to scale up LEC and EDEC devices to become 'green' energy sources.

Tests were conducted on a variety of materials, including the use of high temperature epoxies, poled electret high temperature epoxies, de-ionized water, and electrode gel which is used to obtain good electrical contact between the skin and a sensor for medical testing. When placed between the electrodes of a CPD cell, they successfully produced a current and voltage, some better than others, and some only at high temperatures. The use of electrode gel provided a consistent electrolyte for testing other variables such as work function differences and electrode separation distance. These tests demonstrated the possibility of using solid-state, liquid, or gel electrolytes. In addition to water, and other amphiprotic species, self-ionizing materials such as ethylene glycol and propylene glycol are particularly interesting candidates, however care must be taken in all cases to consider the potential that electrochemical reactions may be involved such as those which corrupted the CPD experiments of both Volta and Kramer. In addition, conservation of energy requires that the cell would cool as electrical energy is being removed. An interesting test might be to place a LEC cell in a high quality instrumentated Dewar to measure the temperature. If the cell does not cool, that could suggest that LENR is occurring which produces heat to offset the energy being removed. It is also interesting to note that the cell temperature for the data plotted in Figs 2a and 2b was 122 °C and in Figs 4a and 4b was 218 K or −55 °C. Additional testing could lead to a better understanding of how the electricity is being produced.

Tests using Pd-H particulate mixed into gel and epoxy electrolytes: During the codeposition process, some Pd-H particulate would not adhere to the cathode electrode, and would settle to the bottom of the solution where it could be collected. A limited number of tests were conducted with this particulate mixed into the gel and epoxy electrolytes. While the ratio of particulate to gel or epoxy was not consistent, these tests produced more output voltage and current than the gel or epoxy alone. Additional testing is required to quantify the benefit of mixing particulate into gel or solid-state electrolyte materials to produce enhanced CPD-EDEC performance.

Tests using different electrode spacing: Although the equations describing gas-ion dynamics do not have an analytic solution when ion diffusion is included, by making some assumptions it is possible to gain an understanding of some of the parameters involved. Electrode spacing is one example and in general, reducing the electrode separation distance reduces the time required for the ions to diffuse to the electrodes [34] which reduces recombination of the ions. However, it also changes the spatially integrated number of ions in the gas that are available for collection as was shown by Thomson in the 1903 edition of his treatise where he writes:

> "Let us consider the special case when the plates are so near together that the loss of ions by diffusion far exceeds that from recombination, ... The total number of free positive ions between the plates is equal to $\int_{-\ell}^{\ell} n\,dx$ and this ... is equal to $(2/3)(q/D)\ell^3$."

Conclusion: A LEC cell is basically a novel contact potential difference, ion diffusion driven device that has demonstrated the ability to spontaneously self-initiate and self-sustain the production of a current and voltage without requiring naturally radioactive materials or electrochemical reactions. A CPD EDEC cell also will produce a sustained

current and voltage when a non-gaseous electrolyte with a continuous source of mobile ions is present between the electrodes. When hydrogen-occluded hydrogen-host-material is added to solid, gel, or fluid electrolytes, an enhanced performance LEC/EDEC cell is produced.

Appendix A. From Volta to the LEC: Important Events in Their Own Words with Emphasis Added

Appendix A.1. Prolog

The electrical behavior of a Lattice Energy Converter (LEC) cell and indeed the LEC effect itself—the spontaneous generation of ionizing radiation by hydrogen occluded electrodeposited hydrogen-host-material (HHM) such as palladium and iron—is so unexpected and counterintuitive that some of the historically important events leading up to the LEC be presented in their authors own words along with interpretive annotation. The development of the lattice energy converter (LEC) cell and its potential as a 'green energy' multi-cell LEC device is an evolution based on many prior achievements. Two distinctly different paths are involved: a) the discovery of contact electrification; and b) that hydrogen-occluded metal lattices have an unusual ability to produce some form of radiation that will ionize gas and fog film. Together, they explain the serendipitous discovery of the LEC effect when a gas electrolysis experiment produced unexpected results.

Appendix A.2. 1800: Volta's Discovery of Contact Electrification is Published in French and English

Excerpt from A Volta, On the Electricity excited by the mere Contact of conducting Substances of different kinds, *Phil Trans Roy Soc Lond*, MDCCC Part II, 403-431; also, *Phil Mag*, **Sep** (1800) 289-311 for the accompanying English translation.

> "30, 40, 60 **pièces**, **ou d'avantage, de cuivre, ou mieux d'argent, appliquées chacune à une pièce d'étain**, ou, ce qui est beaucoup mieux, de zinc, **et un nombre égal de couches d'eau**, ou de quelque autre humeur qui soit meilleur conducteur que l'eau simple, comme l'eau salée, la lessive, & cc. ou des morceaux de carton, de peau, & cc. bien imbibés des ces humeurs;" also "Thirty, forty, sixty, **or more pieces of copper, or rather silver, applied each to a piece of tin** or zinc, which is much better, **and as many strata of water**, or any other liquid which may be a better conductor, such as salt water, ley [lye], & cc. or pieces of pasteboard, skin, & cc. well soaked in these liquids;"

In 1800, Alexandro Volta, an Italian physicist, after several years of research presented the electrophysical concept of the contact electrification of dissimilar metals which he demonstrated by an electroscope of his own design [18]. In the first segment of the quote shown above, Volta described electrophysical cell using tin and silver which are normally insoluble in water and in the second segment of the quote, he described an electrochemical cell involving zinc and silver as the electrodes. At that time, the difference between electrochemical and electrophysical cells was not understood. That is, when metals that have different electrophysical properties, known today as work functions and Fermi levels, and are brought into electrical contact so that their Fermi levels can equilibrate, they become spontaneously electrified. Thus, they produce a Contact Potential Difference (CPD) or Volta potential in the separation between the metals when in electrical contact [26]. Based on this concept Volta proceeded to develop copper (Cu) or silver (Ag) and tin (Sn) electrical cells that could produce a weak voltage and current when water was used as the electrolyte between the dissimilar metal electrodes. However, when the Sn electrodes were replaced with electrochemically active zinc (Zn) electrodes, then in the presence of water or a liquid containing additional ions such as sea water, a much larger voltage and current was produced. Thus, after discovering contact electrification and the manifestation of contact potential difference (CPD), *i.e.*, the electrophysical (ion migration) effect that LEC cells are based upon, Volta went on to develop the electrochemical (oxidation/reduction) cells, *e.g.*, copper or silver and zinc, which performed better than

his CPD cells. To increase the voltage available from his cells, he arranged the electrophysical or electrochemical cells together electrically in series, *e.g.*, one on top of the other to form a column or 'pile.' The original electrophysical piles were eventually mostly forgotten [18] but the electrochemical piles went on to become today's electrochemical batteries.

Appendix A.3. 1866-68: Occlusion of Hydrogen by Palladium (Pd) and Iron (Fe) is Published by T Graham

Excerpts from T Graham, On the Absorption and Dialytic Separation of Gases by Colloid Septa. Action of Metallic Septa at a Red Heat, *Phil. Trans. London*, **156** (1866), 399-439; also, *Proc. Roy. Soc. London*, **15** (1866), 223-, and T Graham, On the Occlusion of Hydrogen Gas by Metals, *Proc Roy Soc*, **16** (1868) 422–427.

> "The absorption of hydrogen was still more obvious when the palladium plate was constituted the negative electrode in acidulated water to a [Bunsen] battery of six cells. The evolution of oxygen gas at the positive electrode continuing copious, the effervescence at the negative electrode was entirely suspended for the first twenty seconds, in consequence of the hydrogen being occluded by the palladium. The final absorption amounted to 200·4 volumes, and was greater in amount than the volume of hydrogen occluded by the same plate heated and cooled in an atmosphere of the gas, which did not exceed 90 volumes."

In 1866 while working at the Royal Mint, Thomas Graham, an English Chemist and Master of the Mint, established thermal procedures for the occlusion or storage of atomic hydrogen in the lattice of palladium (Pd) and iron (Fe) metals. However, electrolysis is a better method, and it is primarily by electrolysis that hydrogen is occluded in the Pd and Fe of LEC devices. It is now generally accepted that molecular hydrogen is adsorbed on the surface of the metal where it dissociates and enters the metal's lattice structure as atomic hydrogen.

Appendix A.4. 1896: Conduction of Electricity Through Ionized Gas is Published

Excerpt from "On the Passage of Electricity through Gases exposed to Röntgen Rays," JJ Thomson and E Rutherford, *Phil Mag* S 5, **42**(258) (1896) 392–407.

> "…, **for a given intensity of radiation the current through the gas does not exceed a certain maximum value whatever the electromotive force may be, the current gets, as it were, 'saturated.'** Thus the limiting current is proportional in the distance between the electrodes, so that when we approach saturation the current will increase as the distance between the electrodes increases,"

In the laboratory, the conduction of electricity through gases has been studied for over 130 years since the discovery of radioactivity by Becquerel [38] in 1896 and Röntgen Rays (X-rays) by Röntgen [39] in 1895. One of the earliest publications that discusses the conduction of electricity is by JJ Thomson and E Rutherford [16] at the Cavendish Laboratory of Cambridge University. However, it should be noted that unlike the observations of Thomson's and Rutherford's experiments, based on experimental results, the conduction of electricity through a LEC cell when a voltage is applied does not saturate at the voltages used in these experiments.

Appendix A.5. 1897: Contact Potential Difference (CPD) is Experimentally Verified and Quantified by Lord Kelvin

Selected excerpt from "Experiments on Electric Properties of Uranium," W Thomson (Lord Kelvin), *Edinb Roy Soc Proc* **xxi** (1897) 417–428 reprinted in *Mathematical and Physical Papers*, Vol 6, J Larmor Ed, 1911,

"Potential differences of uranium-conductance-zero from metallic zero for different metals in air.

Metals	Potential Difference [in] Volt
Polished aluminium (1) immediately after being polished	–1·13
Polished aluminium (1) next day	–1·90
Unpolished zinc	–0·55
Tinfoil	**–0·49**
Unpolished aluminium (1)	–0·41
Polished copper	–0·17
Unpolished copper +0·07	
Carbon	+0·20
Oxidised copper (*a*)	+0·42
Oxidised copper (*b*)	+0·90

It will be observed that the difference of potential observed depends very much on the state of polish of the metal concerned."

In his 1897 paper and a subsequent journal article, William Thomson (Lord Kelvin) [40], a British Mathematician, describes experimental measurements of the CPD between different metals using the radiation from uranium (U) to ionizing the gas between the different metals and a uranium reference metal. This work provides quantitative measurements of the CPD of some chemically dissimilar metal pairs in support of Volta's theory of contact electrification. Also, https://public.wsu.edu/∼pchemlab/documents/Work-functionvalues.pdf

Appendix A.6. 1899: Conduction Equations Including Ion-ion Recombination Neglecting Diffusion

Excerpt from "*On the Theory of the Conduction of Electricity through Gases by Charged Ions*," JJ Thomson. *Phil Mag* S5 **47**(286), (1899), 253–268.

"The electrical conductivity possessed by gases under certain circumstances–as for example when Röntgen or uranium rays pass through the gas, · · ·, or to a piece of metal illuminated by ultra-violet light–**can be regarded as due to the presence in the gas of charged ions, the motions of these ions in the electric field constituting the current."**

JJ Thomson, [29] FRS, a British mathematician, continues the study of the conduction of electricity through gases initially reported by Thomson and Rutherford [16] in 1896. Ion-ion recombination is considered in this work; however, diffusion of the ions is not considered since most experiments use voltages such that the electric field induced drift of the ions is much greater than their diffusion. The differential equations describing the conduction of the gas by charged ions are presented, however, Thomson was not able to find a general analytic solution for the electric field within the gas. Some specific numerical solutions including diffusion were obtained by Tate [23] in 1966. An implicit analytic solution for the distribution of ions in the case that diffusion is neglected was obtained by Rosen and published in a thesis [41] in 1971 and published in1975 [42].

Appendix A.7. 1903: Diffusion of Ions in the Absence of Both Recombination and an Electric Field is Considered by JJ Thomson

Excerpt from *Conduction of Electricity through Gases*, JJ Thomson, 1903

"In addition to the loss of ions arising from the recombination of the positive and negative ions **there will be a further loss due to the diffusion of ions to the sides of the vessel.** Thus suppose the ionized gas is

contained in a metal vessel, **then charges are neutralized by the opposite charge induced on the metal and they thus cease to act like ions**; the layer of gas next to the sides of the vessel is thus denuded of ions, which exist in finite numbers in the gas in the interior; **a gradient in the concentration is thus established and the ions diffuse from the interior to the boundary.**

This is the first mention, that for a cell with plane-parallel electrodes, that electrodes close together would minimize the loss of ions by recombination so that conduction by diffusion would dominate. The analysis shows that in the steady-state the total number of ions between the electrodes is $2q\ell^3/3D$ where separation distance of the electrodes is 2ℓ, the rate of ionization of the gas is *q* ion pair/cm^3/s, and *D* is the coefficient of diffusion, approximately 0.123 cm^2/s and 0.190 cm^2/s for positive and negative dry hydrogen (H_2) ions respectively [31]. However, there is no CPD term in the analysis and thus no sustained current produced by the neutralization of the ions.

Appendix A.8. 1903: E Riecke's Conduction of Gas Equations Including Diffusion are Published

Excerpt from E Riecke, *Über näherungsweise gesättigte Ströme zwischen planparallelen Platten* [On approximately saturated currents between plane-parallel plates], *Ann d Physik*, **12** (1903) 820–827.

"[Let one of two infinite plates which are parallel to each other at the distance *l*, be positively charged, the other connected to the conductive [grounded to earth]. Let the intensity of the electric field enclosed between the plates be F. The air in the space between the plates is ionized, for example, by X-rays or radium rays.

[**Then the following equations result:**]

$$dF/dx = 4\pi\varepsilon(N^+ - N^-),$$
$$v\varepsilon(UN^+ + VN^-)F - \varepsilon d(k^+N^+ - k^-N^-)/dx = c,$$
$$q = vUd(N^+F)/dx - k^+d^2N^+/dx^2 + \alpha N^+N^-,$$
$$q = -vVd(N^-F)/dx - k^-d^2N^-/dx^2 + \alpha N^+N^-.]"$$

Eduard Riecke, a German experimental physicist, publishes the full set of differential equations for the conduction of electricity through a gas confined between plane-parallel electrodes [30]. These equations include terms for the diffusion of the ions. Additionally, he describes a successive approximation method of deriving an analytic solution of the differential equations for the electric field distribution within the gas. This seldom cited German work is translated in an appendix [7] to make it more accessible to researchers interested in the mathematics of the conduction of electricity through gases including diffusion. Note that in Riecke's equations the usual notation for the electric field, *E*, has been replaced by, F, and the mobilities of the ions, $\mu_\pm$, have been replaced by *vU* and *vV* respectively. The usual notations for the diffusion coefficients, $D_\pm$, has been replaced by $k^\pm$. The usual current density, *i*, has be replaced by *c*. The unit system being used is CGS-ESU since the coefficient of *d*F/*dx* in Poisson's equation is $4\pi\varepsilon$ where ε is the unit electric charge.

Appendix A.9. 1916: Irving Langmuir's Explanation of how CPD and an Ionized Gas Produces a Current is Published

Excerpt from I Langmuir, The Relation between contact potentials and electrochemical action, *Trans American Electrochemical Soc*, XXIX(125) (1916) 172–217.

"These relations are illustrated in Fig. 5. **There will be a real difference of potential (about 0.8 volt for Zn and Cu) at the junction *AB*.** Suppose we place an inert gas in the gap between *C* and *F* and ionize this

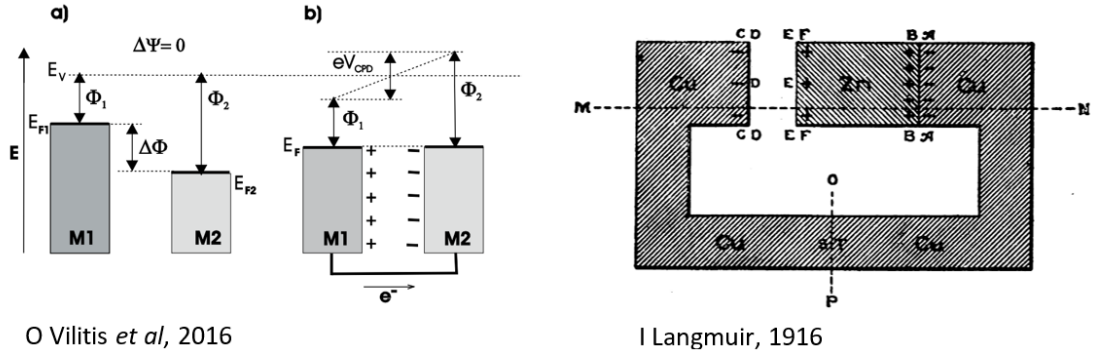


Figure A1. Fig 1a. Explanation of CPD voltage generation [26], Fig. 1b, Example of a CPD device (Fig. 5) from Langmuir [17].

gas by a radioactive substance or in any other manner. **The positive ions will be drawn to *C* [high Φ Cu] and the negative to *F* [low Φ Zn]. . . .. But if the ions can discharge themselves on the plates *C* and *F*, then a current will continue to flow as long as the gas continues to be ionized.** The positive current will flow from *C* to *A*, *B* and *F*, · · ·. If we open the circuit by cutting through the copper conductor at *OP* then a difference of potential will develop between *S* and *T* which will be a measure of the electromotive force of the cell."

When the electrodes are made of materials with different work functions*, Φ, and there is a continuously ionized electrolyte between them, a current will flow between the electrodes when the electrolyte contains both positive and negative mobile ions. Consider the case of polycrystalline zinc (Zn) and 110 face Copper where $\Phi_{Zn} \approx 3.63$ eV and $\Phi_{Cu(110)} \approx 4.48$ eV ($\Delta\Phi = 0.85$ eV)* as illustrated in the above figure by Langmuir.

*https://public.wsu.edu/∼pchemlab/documents/Work-functionvalues.pdf

Appendix A.10. 1932: KK Darrow's Treatise on Electrical Phenomena in Gases is Published

Excerpts from Chapter V of KK Darrow: "Flow of Ions under the Joint Influence of Fields and Concentration-Gradients" in *Electrical Phenomena in Gases*, 1932.

Diffusion of ions for plane-parallel electrodes

"Conceive 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* positives and *q* negatives appearing per unit volume per unit time. . . ..

With too low a potential-difference between the electrodes and therefore too low a fieldstrength, some of the ions will be lost by recombination . . . **or by diffusing to the wrong electrode, positives wandering to the anode and negatives to the cathode.**"

KK Darrow's treatise *Electrical Phenomena in Gases* (Darrow, 1932) is perhaps more important for an understanding of the spontaneous conduction of electricity in a LEC, where the CPD voltage is low and thus the electric field is low, than the Thomsons' *Conduction of Electricity through Gases*, 3^{rd} Ed, Vol I, [31]. In Darrow's treatise he derives from 'first-principles' the same conduction equations that were only presented by Riecke in 1903 without comment. Also, Darrow states for the first time that when diffusion of the ions is considered the conduction is not 'ohmic' *i.e.*,

the current density does not go to zero when the electric field, E, goes to zero since there are still terms involving the diffusion, $D_{\pm}$, of the ions.

It is the active diffusing of the positive ions to the positive ('wrong') electrode and the negative ions to the negative ('wrong') electrode that is the principle determining feature of a LEC's generation of a load current. The greater the voltage developed across the load the greater is the potential between the LEC's electrodes and the more difficult it is for ions to diffuse to the 'wrong' electrodes against the influence of the electric field which causes the ions to drift to the 'right' electrodes which then reduces the current produced by a LEC device. This explains why the power produced in the load resistance has a maximum at an intermediate value of load resistance.

Darrow then goes on to make an important observation about the nature of the electrical conduction in ionized gases.

"What is peculiarly interesting is that E and i do not necessarily vanish together."

This means that the conduction is 'non-ohmic' in the sense that $V = \int E(x)dx$ is not proportional to $I = \int i(S)\, dS$ where S is the cross-sectional area of the current-conduction path.

Appendix A.11. 1950: An Implementation of a CPD Device Using Radioactive Material

Excerpts from PE Ohmart, A method of Producing an Electric Current from Radioactivity, Mound Laboratory MLM-403, (1950) 1-8, *J Appl Phys*, 22(12) (1951) 1504-1505, and Radio Electric Generator, US 2,696,564 filed 27 Jun 1951 and issued 7 Dec 1954.

> "**Experiments have shown that if a cell, made of two electrochemically dissimilar materials separated by a gas, is connected to a current measuring device, a small continuous current will be caused to flow from the more noble to the more active electrode without an external source of voltage when the separating gas is forcibly ionized by exposure to nuclear radiation**. The current thus produced has been found to be dependent on the nature of the electrodes and their surfaces, the type and flux density of the energizing radiation, the type and pressure of the filling gas, and (when excited by gamma-radiation) the gamma stopping power of the electrodes."

See Figs. 1 and 2 of Ohmart's 1964 patent 3,152,254 excerpted below.

Appendix A.12. 1964: Recognition that Radiation Other Than Nuclear Could be Used in a CPD Current Producing Device

Excerpt from PE Ohmart, patent US 3,152,254, Method and Apparatus for converting Ionic Energy Into Electrical Energy, filed 13 Jun 1956 and issued 6 Oct 1964

> "I have since discovered and determined that this type of circuit may be activated to produce current between two chemically dissimilar electrodes in the absence of radioactivity; . . ., **and that the same current creating effect is had if the electrodes are immersed in an ion plasma, however created**."

Ohmart successfully reduced I Langmuir's theoretical observation on a CPD cell containing an ionized gas between the electrode to a practical device that could be used to measure incident radiation (a radiation detector) or an energy producing device when ionizing radiation such as UV light was used to ionize the gas. Despite Ohmart's conduction curves being very similar to the conduction curves of a LEC, Ohmart's devices differ from LEC devices since they require either an external source of UV radiation or, alternatively, external, or internal radioactive material. In addition,

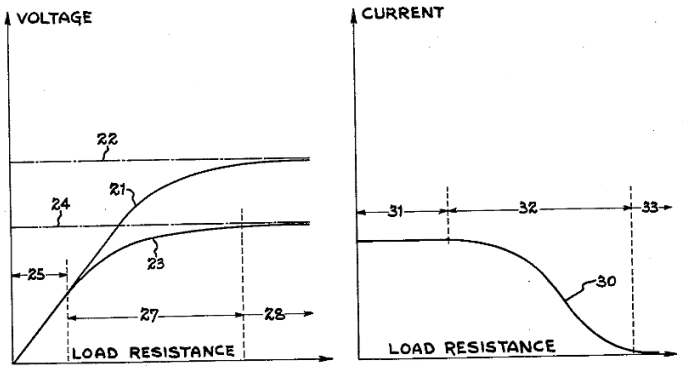


Figure A2. Figs. 1 and 2 of Ohmart's US 3,152,254 where he used an external ionization source are similar to data produced by a LEC with active HHM.

as with Langmuir, Ohmart is focused on using ionized gas and he does not consider the use of a liquid, a gel, or a solid-state electrolyte that contains mobile ions.

Appendix A.13. 1966: PA Tate's Analysis of the Effect of Diffusion of Ions is Published

Excerpt from PA Tate, Effect of Diffusion on the Saturation Curve of a Plane Parallel Ion Chamber, *Phys Med Biol*, **11**(4) (1966) 521–532.

> "**Equations which include diffusion effects are derived for the electric field in an irradiated ion chamber. Numerical solutions are obtained by machine computer for degrees of saturation from 0.2 to 0.93.** These solutions enable calculations to be made which agree closely with the experimental results of Shevyrev".

A major attempt to solve the ionized-gas conduction equations that includes the effect of ion diffusion was in 1966. In this work Tate combines the various relevant different equations into one 4^{th}-order non-linear differential equation for the electric field to be solved numerically. In the process of combining the different equations Tate assumes "for the sake of simplicity" that the mobilities of the positive and negative ions, $\mu_{\pm}$, are equal. This last assumption results in the positive and negative diffusion coefficients, $D_{\pm}$, being equal by the Einstein relationship, $D_{\pm} = \mu_{\pm} k_{eV} T$ where k_{eV} is Boltzmann's constant in units of eV/K and T is the temperature of the ions in kelvin. Tate further states "These assumptions are not expected to alter the problem greatly as long as the current carriers are ions rather than electrons." Thus, $(D_2 - D_1)dn/dx$, which is the term that drives LEC conduction also nearly vanishes. Additionally, Tate assumes that "we will require as usual in diffusion problems, that the concentration of ions of each type be zero." This assumption does not appear to be consistent with the LEC device requirement that positive ions be neutralized at the positive electrode while negative ions are neutralized at the negative plate to form the CPD-LEC device load current.

Appendix A.14. 1975: Rosen and George: Analytic Distribution of Ions Including Recombination but Without Diffusion

Excerpt from E Rosen, EP George, Ion Distribution in Plane and Cylindrical Chambers, *Phys Med Biol*, 20(6) (1975) 990-1002.

"2. Chamber characteristics: The plane-parallel and cylindrical ion chambers · · ·. · · · are considered to be infinitely long so that end effects can be neglected. The cylindrical chamber consists of coaxial electrodes of inner radius *a* and outer radius *b*. The plane chamber has parallel electrodes with spacing *u* and width *w*. Subscripts *p* and *c* refer to the plane-parallel and cylindrical chambers respectively.

Each chamber is assumed to contain a stationary medium in which ions are produced uniformly throughout the volume at a the rate *Q* per unit volume per unit time. The ions have concentration *N*, mobility μ, drift velocity *v*, volume recombination coefficient α, diffusion coefficient *D* and carry an electrical charge *e*. · · ·. The potential applied across the chamber is *V*.

3. Diffusion: An estimate of the relative importance of diffusion in both chambers can be obtained as follows. The average lifetime τ of particles against diffusion to the walls of each chamber is given by McDaniel (1964a) [34] as:

$$\tau_p = \{D\pi^2[(1/u)^2 + (1/w)^2]^{-1}; \tau_c = (1/D)(b/2 \cdot 405)^2. \quad (1)$$

The time *T* [neglecting space-charge] required to collect an ion from one boundary to the other is given by

$$T_p = u^2/\mu V; \quad T_c = \ln(b/a)(b^2 - a^2)/2\mu V. \quad (2)$$

For chambers operating at room temperature, the Einstein relation (McDaniel 1964b) [34] becomes . . . *D* = 0.0254μ. As the minimum value of *V* to be adopted experimentally in the present instance is 100V, the ratio T/τ is found from eqns. (1) and (2) to be less than 0.004 for both chambers. Under these conditions diffusion is completely negligible, and accordingly is here omitted."

When this analysis is repeated for typical experimental InovL plane-parallel LECs the dimensions are $u \approx 0.1$ cm, w ≈ 3 cm, $V \approx 1.0$ mV, and with H_2 gas in the cell the harmonic mean mobility of the ions is $\mu_{hm} \approx 2\mu_1\mu_2/(\mu_1 + \mu_2) \approx 6.67$ cm^2/V·s where $\mu_1 \approx 5.78$ cm^2/V·s and $\mu_2 \approx 7.90$ cm^2/V·s [31]. Thus, for a typical InovL LEC cell

$$\tau_p \approx 0.00548\text{s}, T_p = 1.50\text{s}, \text{and}$$
$$\tau_p/T_p \approx 0.00548/1.50 \approx 0.00365.$$

Therefore, since the diffusion time, τ_p, is smaller than the ion drift time, T_p, the cell is diffusion limited. However, as the 'open circuit' voltage, *V*, approaches 1.0 volt, the time constants become

$$\tau_p \approx 0.00548\text{s}, Tp = 0.0015\text{s}, \text{and}$$
$$\tau_p/T_p \approx 0.00548/0.001.5 \approx 3.65.$$

At this higher voltage, the drift time, T_p, is smaller than the diffusion time, τ_p, and the cell is no longer diffusion limited but ion drift limited so that the load current decreases as the cell voltage increases since the ions can no longer diffuse to the 'wrong' electrodes. **This change in behavior as a function of LEC device voltage is shown in Figs. 2a and 2b. Note that the peak power output occurs midway between the low and high LEC device voltages where the ratio of diffusion to drift time is approximately equal to 1. Furthermore, the critical cell design parameter is the electrode separation distance.**

Appendix A.15. 1989: Pons and Fleischman Reported Nuclear Fusion from Electrolyzed Pd/D

*M Fleischmann, S Pons, Electrochemically induced nuclear fusion of deuterium, Journal of Electroanalytical Chemistry, **261**(2A) (1989) 301–308.*

> **"The observation of the generation of neutrons and of tritium from electrochemically compressed D^+ in a Pd cathode is in itself a very surprising result** $\cdots$."

These experiments also produced more energy in the form of heat ('excess' enthalpy) than that which could be accounted for by chemical reactions alone. This phenomenon was dubbed 'cold fusion' by the press and Low Energy Nuclear Reactions (LENR) by the scientists and researchers working in the field. Since 1989 there have been 25 international conferences on cold fusion (ICCF) with ICCF-25 held in Poland in 2023. Visit the website LENR-CANR.org for a library of papers about cold fusion. CANR is an abbreviation of "chemically assisted nuclear reactions."

Appendix A.16. 1996 The Bhabha Atomic Research Centre (BARC) Finds Unexplained Radiation from Hydrogen Occluded Metals, in Particular Palladium (Pd)

Excerpt from RK Rout *et al*, Reproducible, Anomalous Emissions from Palladium Deuteride/Hydride, *Fusion Technol* **30** (1996) 271–282.

> "**Each and every palladium sample loaded/reloaded either with hydrogen or deuterium was observed to fog radiographic films kept in its close proximity in air.** Strangely, even with ten layers of black paper (thickness ≈63 mg/cm^2) as a filter between film and sample, fogging was observed. On the other hand, no fogging could be observed even when thin beryllium foil (≈1.4 mg/cm^2), three layers of transparent polyester foils (≈10 mg/cm^2), or thin aluminized polycarbonate (0.3 mg/cm^2) were employed as filters. **Several experiments have been performed to identify the phenomenon responsible for fogging. These experiments appear to rule out any of the known mechanisms, suggesting a new, strange, and unknown phenomena**.
>
> . . . .
>
> **The phenomena, though most easily reproducible in palladium, are perhaps more universal and may also be occurring when H_2/D_2 is loaded into other metals.**
>
> **All the mechanisms (known to us) which might have fogged the films, were considered and ruled out. Therefore, it is proposed that some new, unknown agency emitted from loaded palladium is responsible for fogging.**"

Similar film fogging in air was observed by Miles at the Naval Weapon Center [43] and by Szpak at the Naval Command, Control and Ocean Surveillance Center (later SPAWAR) [44] after palladium (Pd) was co-electrodeposited on nickel (Ni) screen. In these experiments the fogged film produced an image of the deposited screen. This indicates that the range, in air, of the fogging radiation may be short. Additionally, "The cathodically polarized Pd/D system emits X-rays with a broad energy distribution [7–40 keV] and with an occasional emergence of recognizable peaks" [45]. InovL researchers believe that the phenomenon responsible for the fogging of film and the production of X-rays may be the same phenomenon that ionizes the H_2/D_2 gas as well as air for lattice energy converters (LECs).

Appendix A.17. 2003: Hot Spots and Mini-explosions in Electrolyzed Co-deposited Pd are Reported by SPAWAR

Excerpt from S Szpak *et al*, Polarized D+/Pd-D2O system: Hot spots and mini-explosions. In PI Hagelstein, SR Chubb, Eds, *Condensed matter nuclear science*: proceedings of the 10^{th} international conference on cold fusion, 2003, World Scientific (2006)13-22.

> **"Two types of activities occurring within the polarized D^+/Pd–D2O system, *viz*. the presence of localized heat sources (hot spots) and associated with them mini–explosions,** are described. The "birth and death" of hot spots is monitored by IR imaging while the mini–explosions are displayed by the voltage spikes exhibited by a piezoelectric [polarized ferroelectric] substrate onto which a Pd/D film was co–deposited."

A video of an IR camera observed electrically co-deposited Pd on a Ni screen undergoing electrolysis in a D_2O solution of $PdCl_2$ and LiCl. [46]. As shown in the IR camera image, the Pd on Ni screen is hotter than the electrolyte and the hot spots come and go as a function of time. Also note, the authors of the report state that the mini-explosions voltage pulses are registered by the transducer due to its piezoelectric properties, but the authors of this paper suggest that a more plausible explanation is that the transducer voltage is due to the pyroelectric properties of the electrically polled ferroelectric ceramic materiel (lead titanate zirconate, PZT). Scanning electron microscope images of electrolyzed Pd made after testing show what look like tiny explosions of molten Pd.

Appendix A.18. 2013 Gordon and Whitehouse Discover that Pd-D Prepared by Co-deposition Emits Radiation that Would Ionize Deuterium Gas

The discovery that an electrode prepared by co-deposition of Pd-D was initially discovered by Gordon and Whitehouse while conducting experiments in 2013. Many experiments were conducted to characterize and verify these surprising results. Announcement was delayed until after Jean-Paul Biberian had replicated these results.

Appendix A.19. 2020 The Discovery and Properties of the Lattice Energy Converter (LEC) is Disclosed

The first public announcement was at the 2020 French RNBE (LENR) conference in Paris France, organized by the French Society for Nuclear Science in Condensed Matter (SFSNMC). Since French was the conference language, Jean-Paul presented the Gordon and Whitehouse LEC paper as well as his replication of these surprising results.

Appendix A.20. Epilog

The surprising discovery of the LEC has technological roots going back more than 200 years. Multiple opportunities were missed by researchers for multiple reasons. Volta was initially studying electrophysical contact potential difference electrification when he discovered that certain materials worked better than others which led to the electrochemical battery. Thomson and others were studying conduction through a gas using an applied electric field that rendered diffusion effects insignificant. Ohmart used an external source of ionization as described in his patents. The discovery by Fleischmann and Pons showed that nuclear reactions could be produced at low energy, and researchers at the Bhabha Atomic Research Center (BARC) realized that radiation was produced that would fog film, but they were unable to identify or detect it with instrumentation that was much more sensitive than the film being fogged. Gordon and Whitehouse were attempting to conduct high temperature gas electrolysis of Pd that was occluded with hydrogen when they realized that more current was being conducted than the radioactive sources that were in the cell to ionize the gas could produce. After additional experiments, they determined that the Pd that was occluded with deuterium was the source of the ionizing radiation. The identification of the ionizing radiation remains a mystery to this day, however, that original cell shown in Fig. 1 has been operating continuously since 2013 and it continues to produce gaseous ions which are collected as current. In that regard, we are like the early cave men who knew what would burn, and how to light a fire to cook their food, provide light, and provide warmth, even though they didn't know the physics involved. That didn't come until several hundred thousand years later when Lavoisier showed that fire was a rapid oxidation chemical reaction. We don't want to wait until a proven and accepted theory that explains how the ionizing radiation in a metal lattice that is occluded with hydrogen is produced. Our experiments, and those of replicators,

prove that this phenomenon exists and with additional research might lead to a low cost and abundant 'green' energy source for the world.

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