

Empirical Relation of the Fine-Structure Constant with the Transference Number Concept

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Abstract

The fine-structure constant of $1/137$ is puzzling and has never been fully explained. When the interaction coefficient is $1/137$, the transference number should be $136/137$. With the transference number concept, we noticed that we must examine the constant of $1/136$ instead of $1/137$ to discover an empirical relationship in which the fine-structure constant is related to the mass ratio of electrons and quarks. Then, the physical meaning of this empirical relationship is discussed.

Keywords

Wagner's Equation, Fluctuation and Dissipation Theory, Boltzmann Distribution, Maxwell's Demon, Additional Thermodynamic Law

1. Introduction

Previously, we tried to explain quantum physics using classical thermodynamics [1] [2]. However, these discussions were lacking evidential support, prompting us to search for this evidence.

Solid-oxide fuel cells (SOFCs) directly convert the chemical energy of fuel gases, such as hydrogen and methane, into electrical energy. SOFCs use a solid-oxide film as the electrolyte, and oxygen ions serve as the main charge carriers. Typically, yttria-stabilized zirconia (YSZ) is used as the electrolyte material in these cells. The open-circuit voltage (OCV) of the YSZ electrolyte is equal to the Nernst voltage (V_{th}) of 1.15 V at 1073 K. However, using samaria-doped ceria (SDC) electrolytes, the OCV is approximately 0.8 V. The low OCV was calculated using Wagner's equation, which is based on the chemical equilibrium

theory. Wagner's equation [3] [4] is

$$J_{O_2} = -\frac{RT}{16F^2L} \int_{\ln pO_2^{anode}}^{\ln pO_2^{cathode}} \frac{\sigma_{el}\sigma_{ion}}{\sigma_{el} + \sigma_{ion}} d \ln pO_2 \quad (1)$$

where J_{O_2} and pO_2 are the O_2 flux and the O_2 partial pressure, respectively; $pO_2^{cathode}$ and pO_2^{anode} are the O_2 partial pressures at the cathode and anode, respectively; R , T , and F are the gas constant, the absolute temperature, and Faraday's constant, respectively; L is the thickness of the membrane or film; and σ_{el} and σ_{ion} are the conductivities of the electrons and oxygen vacancies, respectively.

From Equations (1), Equations (2) and (3) can be deduced [5]:

$$OCV = V_{th} - R_i I_i \quad (2)$$

where R_i and I_i are the ionic resistances of the electrolyte and the ionic current, respectively.

$$OCV = \frac{RT}{4F} \int_{\ln pO_2^{anode}}^{\ln pO_2^{cathode}} t_{ion} d \ln pO_2 \quad (3)$$

Parameter t_{ion} is expressed as

$$t_{ion} = \frac{\sigma_{ion}}{\sigma_{el} + \sigma_{ion}} \quad (4)$$

However, σ_{el} is a function of the O_2 partial pressure [6]:

$$\sigma_{el} = \sigma_{ion} \left(\frac{pO_2}{pO_2^*} \right)^{-\frac{1}{4}} \quad (5)$$

where pO_2^* corresponds to the oxygen partial pressure at which $t_{ion} = 1/2$. When t_{ion} is constant in the electrolytes,

$$OCV = t_{ion} \times V_{th} \quad (6)$$

The low OCV was thought to be due to the low value of the ionic transference number (t_{ion}). However, experimentally, I_i in Equation (2) is negligible [6] [7] [8] [9] [10]. Considering the direction of the electrical field, there are serious problems in Wagner's equation [5] [10]. Therefore, the voltage loss should be explained by other reasons.

Over the past two decades, the understanding of nonequilibrium thermodynamics has been enhanced by fluctuation and dissipation theorems such as the Jarzynski and Crooks relations [11] [12]. The autonomous Maxwell's demon concept was proposed by Jarzynski [13], and we independently discovered the equation for this concept [14]. In our equation, t_{ion} remains important. In addition, we determined the empirical relationship and discussed the physical meaning of this empirical relationship.

2. Equation for Autonomous Maxwell's Demons

2.1. Main Problems in Wagner's Equation

According to Michael Faraday, the direction of the electrical field is from the

anode to the cathode. In the 1950s, Wagner studied mixed conductors with positively and negatively charged ions. However, Wagner's equation was used for doped ceria electrolytes in which there are two negative carriers (oxygen ions and electrons). The ionic current (I_p) and electron drift current (I_{e_drift}) flow from the cathode to the anode. Only the electron diffusion current ($I_{e_diffusion}$) can flow from the anode to the cathode. A schematic drawing of the directions of I_p , I_{e_drift} and $I_{e_diffusion}$ is presented in **Figure 1**. According to Weppner [15], there should be a delay for $I_{e_diffusion}$:

$$\tau = \frac{L^2}{\tilde{D}} \quad (7)$$

where τ , L , and \tilde{D} are the equilibrium time, sample length, and chemical diffusion coefficient, respectively. According to Wang [16], \tilde{D} is 3.2×10^{-6} cm²/s at 1073 K. Therefore, using 1-mm-thick SDC electrolytes, τ should be 52 min at 1073 K. However, such a delay has been never observed during the transient process, so the existence of $I_{e_diffusion}$ can be disproved [5] [10].

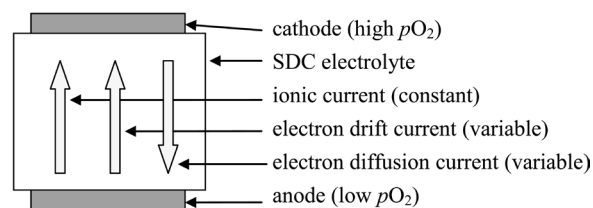
2.2. Autonomous Maxwell's Demons Explanation

We discovered the following empirical equation using SDC electrolytes [14]:

$$OCV = V_{th} - \frac{E_a}{2e} \quad (8)$$

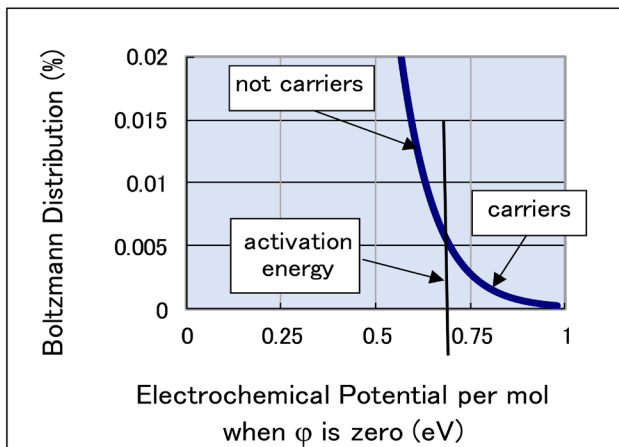
where e is elemental charge. E_a is the ionic activation energy, which is 0.7 eV for SDC electrolytes. Therefore, the OCV in Equation (1) is 0.80 V (=1.15 V – 0.7 eV/2e). This equation is explained in **Figures 2-4**. The Boltzmann distribution of oxygen ions in the electrolyte at 1073 K is displayed in **Figure 2**. The ions with energies exceeding E_a become carriers (hopping ions). **Figure 3** presents an incorrect carrier distribution. The Boltzmann distribution cannot be separated using passive filters because of the phenomenon known as “Maxwell's demon”, and an accurate distribution is provided in **Figure 4**. The loss of Gibbs energy is illustrated in **Figure 3**. Equation (8) is correct, when t_{ion} is zero. When t_{ion} is not zero, the equation for autonomous Maxwell's demon [14] [17] is

$$OCV = V_{th} - (1 - t_{ion}) \times \frac{E_a}{2e} \quad (9)$$



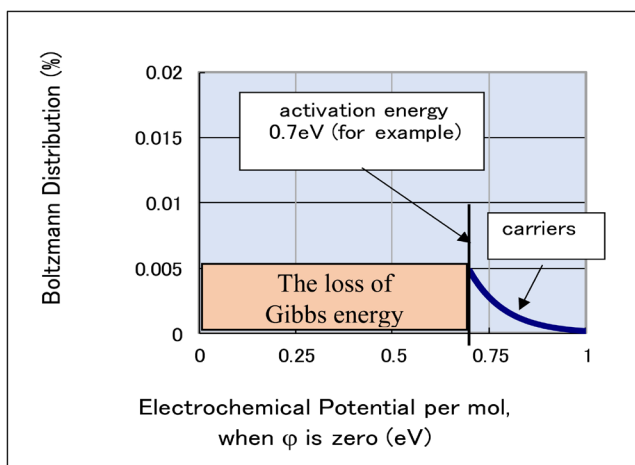
The direction of I_{e_drift} is the same as that of I_p .

Figure 1. Schematic drawing indicating the directions of I_p , I_{e_drift} and $I_{e_diffusion}$ for the open-circuit case.



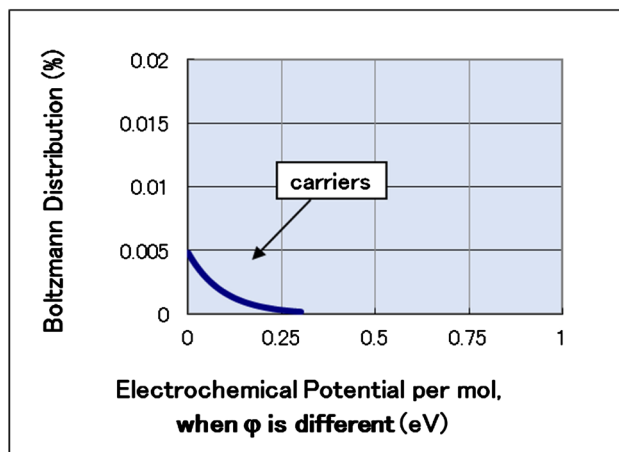
Ions with energies exceeding the ionic activation energy are converted into charge carriers (*i.e.*, hopping ions).

Figure 2. Boltzmann distribution at 1073 K.



This distribution is forbidden according to Maxwell's demon.

Figure 3. Forbidden distribution of hopping ions.



The shape of the distribution in this figure should be the same as the shape of the distribution in **Figure 4**.

Figure 4. Correct distribution of hopping ions.

3. Empirical Relations of the Fine-Structure Constant with the Transference Number Concept

The fine-structure constant (α) is

$$\alpha = \frac{e^2}{4\pi\epsilon_0\hbar c} \quad (10)$$

where π , \hbar , c and ϵ_0 are the mathematical constant pi, the reduced Planck constant, the speed of light in a vacuum and the electric constant or permittivity of free space, respectively.

$$R_K = \frac{h}{e^2} \quad (11)$$

Here, R_K is the von Klitzing constant.

$$Z_0 = \frac{1}{\epsilon_0 c} \quad (12)$$

Here, Z_0 is the characteristic impedance. Therefore,

$$\alpha = \frac{Z_0}{2R_K} \quad (13)$$

When the interaction coefficient is 1/137, the transference number should be 136/137. The parameter t_{ion} is expressed as

$$t_{ion} = \frac{\sigma_{ion}}{\sigma_{el} + \sigma_{ion}} = \frac{R_{el}}{R_{el} + R_{ion}} \quad (14)$$

where R_e and R_{ion} are the resistance values for electrons and ions, respectively. Here, σ_{ion} can be defined even when the ions are blocked to move. In Equation (13), we assumed that the main carriers are electrons that must move with two unknown carriers belonged to the environment. Then, the transference number unknown carriers is

$$t_{unknown} = \frac{\frac{R_{el}}{2}}{\frac{R_{el}}{2} + R_{unknown}} = \frac{R_{el}}{2\left(\frac{R_{el}}{2} + R_{unknown}\right)} \quad (15)$$

where $R_{unknown}$ is the resistance of unknown particles belonged to the environment. Equation (15) is similar to Equation (13), and α^{-1} is 137.035. Therefore,

$$\frac{\frac{R_{el}}{2}}{R_{unknown}} = 136.035 \quad (16)$$

Next, we consider the mobility (μ):

$$\sigma = ne\mu \quad (17)$$

where n is the number of carriers.

$$2n_{el} = n_{unknown} \quad (18)$$

Here, n_{el} and $n_{unknown}$ are the number of electrons and the number of unknown particles, respectively.

$$\mu = \frac{e}{m^* \tau} \quad (19)$$

Here, m^* is the carrier effective mass, and τ is the average scattering time. When τ is constant,

$$\frac{m_{unknown}}{m_{el}} = 136.035 \quad (20)$$

where m_{el} and $m_{unknown}$ are the mass of electrons and the mass of unknown particles, respectively, and m_{el} is 0.511 MeV. Therefore, we must search for the mass with an energy value of 69.50 MeV ($=0.511 \times 136$). The rest mass of a negatively charged pion has an energy of 139.57 MeV. Then, consider the following equation:

$$m_{\pi^-} = 2m_{quark} + m_{el} \quad (21)$$

where m_{π^-} and m_{quark} are the mass of the negatively charged pion and the mass of quarks, respectively. From Equation (21), m_{quark} is 69.53 MeV, which is similar to 69.50 MeV. Therefore, our empirical equation is

$$\frac{m_{quark}}{m_{el}} = \frac{1}{\alpha} - 1 \quad (22)$$

4. Discussion

We proposed a model in which there should be one free electron and two quarks belonged to the environment. Electrons receive the 1/137 energy of photons in the presence of an electrical field. Two quarks receive the 136/137 energy of photons. However, movement of the two quarks with the usual energy is blocked for unknown reasons. Thus, the 136/137 energy of photons should diffuse to the environment, meaning that the transference number of the space for electrons is 136/137, instead of 1, in the presence of an electrical field. We proposed that the quantity of 257,934 ohms (from the calculation of $258,123 - (377/2)$) should be measured.

When two quarks can move with higher energy, the interaction coefficient of quarks should be 136/137 and the transference number of quarks should be 1/137. This is the explanation for the strong interaction. The diffusion response time of the mixed electronic and quark conductors depend exponentially on the distance. So, Yukawa potential can be explained.

5. Conclusion

Using the transference number concept, we proposed an empirical relationship in which the fine-structure constant is related to the mass ratio of electrons and quarks. This empirical equation is determined to be correct with a 99.96% (69.50/69.53) accuracy. Furthermore, we proposed that the quantity of 257,934 ohms should be measured.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- [1] Miyashita, T. (2011) Quantum Physics Can Be Understood in Terms of Classical Thermodynamics. *Journal of Modern Physics*, **2**, 26-29. <https://doi.org/10.4236/jmp.2011.21005>
- [2] Miyashita, T. (2017) Bell's Non-Locality Theorem Can Be Understood in Terms of Classical Thermodynamics. *Journal of Modern Physics*, **8**, 87-98. <https://doi.org/10.4236/jmp.2017.81008>
- [3] Wagner, C. (1975) Equations for Transport in Solid Oxides and Sulfides of Transition Metals. *Progress in Solid State Chemistry*, **10**, 3-16. [https://doi.org/10.1016/0079-6786\(75\)90002-3](https://doi.org/10.1016/0079-6786(75)90002-3)
- [4] Bouwmeester, H.J.M. and Burggraaf, A.J. (1997) Dense Ceramic Membranes for Oxygen Separator. In: Gellings, P.J. and Bouwmeester, H.J.M., Eds., *The CRC Handbook of Solid State Electrochemistry*, CRC Press, New York, 481-553.
- [5] Miyashita, T. (2017) Equilibration Process in Response to a Change in Anode Gas Using Thick Sm-Doped Ceria Electrolytes in Solid-Oxide Fuel Cells. *Journal of Electrochemical Society*, **164**, E3190-E3199 E. <https://doi.org/10.1149/2.0251711jes>
- [6] Kudo, T. (1997) Survey of Types of Solid Electrolytes. In: Gellings, P.J. and Bouwmeester, H.J.M., Eds., *The CRC Handbook of Solid State Electrochemistry*, CRC Press, New York, 195-221. <https://doi.org/10.1201/9781420049305.ch6>
- [7] Miyashita, T. (2006) Necessity of Verification of Leakage Currents Using Sm Doped Ceria Electrolytes in SOFCs. *Journal of Materials Science*, **41**, 3183-3184. <https://doi.org/10.1007/s10853-006-6371-8>
- [8] Miyashita, T. (2011) Unchanged OCV Requires Concepts Considering Electrode Degradation Using Sm-Doped Ceria Electrolytes in SOFCs. *Electrochemical and Solid-State Letters*, **14**, 1-4. <https://doi.org/10.1149/1.3581208>
- [9] Miyashita, T. (2014) A Current-Independent Constant Anode Voltage Loss Using Sm-Doped Ceria Electrolytes in SOFCs. *ECS Transactions*, **59**, 53-61. <https://doi.org/10.1149/05901.0053ecst>
- [10] Miyashita, T. (2017) Current-Voltage Relationship Considering the Direction of the Electrical Field in Mixed Ionic-Electronic Solid Conductors. *ECS Transactions*, **80**, 1057-1072. <https://doi.org/10.1149/08010.1057ecst>
- [11] Jarzynski, C. (1997) Nonequilibrium Equality for Free Energy Differences. *Physical Review Letters*, **78**, 2690-2693. <https://doi.org/10.1103/PhysRevLett.78.2690>
arXiv: cond-mat/9610209
- [12] Crooks, G.E. (1999) Entropy Production Fluctuation Theorem and the Nonequilibrium Work Relation for Free Energy Differences. *Physical Review E*, **60**, 2721-2726. <https://doi.org/10.1103/PhysRevE.60.2721>
arXiv: cond-mat/9901352
- [13] Jarzynski, C. (2012) Work and Information Processing in a Solvable Model of Maxwell's Demon. *Proceedings of National Academy of Sciences of the United States of America*, **109**, 11641-11645. <https://doi.org/10.1073/pnas.1204263109>
- [14] Miyashita, T. (2005) Empirical Equation about Open Circuit Voltage in SOFC. *Journal of Materials Science*, **40**, 6027. <https://doi.org/10.1007/s10853-005-4560-5>

- [15] Thangadurai, V. and Weppner, W. (2004) Ce_{0.8}Sm_{0.2}O_{1.9}: Characterization of Electronic Charge Carriers and Application in Limiting Current Oxygen Sensors. *Electrochimica Acta*, **49**, 1577-1585. <https://doi.org/10.1016/j.electacta.2003.11.019>
- [16] Wang, S., Kobayashi, T., Dokiya, M. and Hashimoto, T. (2000) Electrical and Ionic Conductivity of Gd-Doped Ceria. *Journal of Electrochemical Society*, **147**, 3606-3609. <https://doi.org/10.1149/1.1393946>
- [17] Miyashita, T. (2019) Open-Circuit Voltage Anomalies in Ytria-Stabilised Zirconia and Samaria Doped Ceria Bilayered Electrolytes. (To Be Published)