Effect of strength of gravitational field on electrode processes

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Abstract

Relativistic thermodynamics and kinetics for electrode processes have been developed to explain time dilation in electrode processes. For a moving observer moving at fractions of the speed of light, cell potential is observed to decrease. This results in slower oxidation and reduction of ions at the respective electrodes. The newly formulated Lorentz transformation of the electrode and cell potential is explained in terms of the generation of spin 2-boson gravitons from the fusion of spin-1 boson virtual-photons followed by their eventual escape in higher dimensions. Gravitational transformations of cell potential and electrochemical rate constants are also derived that explain gravitational time dilation in electrode processes. These gravitational transformations show a decrease in the cell potential and electrochemical rate constants at the lower gravitational field. The dropping of cell potential at the lower gravitational field is also explained in terms of the greater flux of gravitons escaping into higher dimensions at lower gravitational fields than at higher gravitational fields. Daniel's cell is mentioned as a numerical example to show the quantitative effect of relativistic and gravitational time dilation on cell potential.

Key Words

relativistic cell potential; gravitational cell potential; time dilation; graviton; virtual photon.
Introduction

Electrochemistry is an interdisciplinary science which comes from the marriage of electrical physics and chemistry [1]. Majorly in electrochemistry, redox reactions (oxidation and reduction) occurring at the interface of electrode and electrolyte are studied which occurs in the liquid phase. Electrochemical reactions occurring at the surface of the electrode can be broadly classified in two categories non-spontaneous and spontaneous redox reactions. Non-spontaneous redox reactions are carried out by passing an electric current through the cell by applying at least threshold potential across the electrodes of the cell while spontaneous redox reactions govern on their own when electrodes are brought in contact with a suitable electrolyte which generates a potential difference across the electrodes that lead to a flow of electric current through the external circuit [2]. Relativistic thermodynamics and kinetics have been formulated to explain time dilation for chemical reactions in a moving frame of reference [3-4]. Relativistic time dilation is one of the basic foundations of the special theory of relativity [5]. In the relativistic theory of chemical kinetics Lorentz transformation of rate constant and thermodynamic state functions have been formulated which are compatible with time dilation phenomenon, which is an experimentally verified fact [6]. Similarly, gravitational time dilation which comes from the general theory of relativity is also an experimentally verified fact reveals that clocks tick slower at the lower gravitational field than at higher gravitational fields [7-8]. Gravitational time dilation will thus also affect the rate of molecular processes at different gravitational fields. Effect of the strength of the gravitational field on the rates of reactions has been formulated in terms of gravitational transformations of rate constants, activation energy and thermodynamic state functions [9]. The present paper is an attempt to formulate Lorentz and gravitational transformations that can explain relativistic and gravitational time dilation in the kinetics of electrochemical phenomenon. In the present paper, all the variables with subscript o refer to the inertial frame of reference $K_o$ with the observer at rest while variables with subscript u refer to the inertial frame $K_u$ with the observer moving at relative speed.u. All Lorentz transformations are defined in terms of a factor “$\gamma = (1 - u^2/c^2)^{-1/2}$ “. While to explain gravitational time dilation all the variables for observer $K_l$ with radial coordinate r is the lower gravitational field of massive planet M are described by subscript l with reference to observer $K_h$ at the higher gravitational field; for which variables are described by subscript h. Their magnitude at different positions in gravitational fields is mathematically related with a factor defined as “$\xi = (1 - 2GM/rc^2)^{-1/2}$ “.

Theory

To formulate a theory that can explain time dilation for the electrochemical process from an eye of moving observer, let consider following reaction occurring on the surface of an arbitrary electrode [1].

\[
\text{O} + e^- \rightleftharpoons \text{R}
\]

Let in above electrode process specie O and R is being involved in one electron transfer process. Free energy associated with above one electron electrode process for moving observer can be formulated as [2,10],

\[
\Delta G_u = -nFE_u
\]
As free energy is proved to be Lorentz variant i.e. \( \Delta G_u = \gamma^{-1} \Delta G_0 \) [3-4], it is observed to be less for moving observer. Since according to the special theory of relativity laws of physics holds good in all inertial frames. So to hold this basic postulate of the special relativity electrode potential becomes Lorentz variant i.e.

\[
E_u = \gamma^{-1}E_o
\]  
(2)

Rate constants of forward and backward reaction can be formulated in terms of Arrhenius factor and free energy of activation as [11-12],

\[
(k_f)_u = (A_f)_u \exp\left(-\left(\Delta G_{0a}^+\right)_u/R_uT\right) \exp\left[-\alpha(E_u - E^0_u/R_uT)\right]
\]  
(3)

\[
(k_b)_u = (A_b)_u \exp\left(-\left(\Delta G_{0b}^+\right)_u/R_uT\right) \exp\left[(1 - \alpha)(E_u - E^0_u/R_uT)\right]
\]  
(4)

For a special case \( E_u = E^0_u \) rate constant for forward and backward reaction become equal i.e.

\[
(k_0)_u = (A_b)_u \exp\left(-\left(\Delta G_{0b}^+\right)_u/R_uT\right) = (A_f)_u \exp\left(-\left(\Delta G_{0a}^+\right)_u/R_uT\right)
\]  
(5)

On substitution of Lorentz transformation of Arrhenius factor, ideal gas constant free activation energy in Eq. (5) gives same Lorentz transformation of threshold rate constant i.e. \( (k_0)_u = \gamma^{-1}(k_0)_o \). Eq.s (3) and (4) can be written in more contact form as [1-2].

\[
(k_f)_u = (k_0)_u \exp\left[-\alpha(E_u - E^0_u/R_uT)\right]
\]  
(6)

\[
(k_b)_u = (k_0)_u \exp\left[(1 - \alpha)(E_u - E^0_u/R_uT)\right]
\]  
(7)

On substitution of Lorentz transformation of Electrode potential, ideal gas constant and threshold rate constant in Eq.s (6) and (7) gives the same Lorentz transformation of the rate constant as formulated earlier [3].

\[
(k_f)_u = \gamma^{-1}(k_f)_o
\]  
(8)

\[
(k_b)_u = \gamma^{-1}(k_b)_o
\]  
(9)

Butler-Volmer relation that explains total current flow in an electrode process for moving observer can be stated as [11],

\[
i_u = NFA(k_0)_u \left[\exp\left[-\alpha(E_u - E^0_u/R_uT)\right] - \exp\left[(1 - \alpha)(E_u - E^0_u/R_uT)\right]\right]
\]  
(10)

On substitution of Lorentz transformation of Electrode potential, ideal gas constant and threshold rate constant in Eq. (10) gives the Lorentz transformation of current as [3],

\[
i_u = \gamma^{-1}i_o
\]  
(11)

So due to the drop in the electric potential for moving observer net current flow will slow down. The moving observer will find net charge transfer per unit time is less than compared to in its own frame of reference because for moving observer clock of the system at rest will tick slower.
Electrode potential associated with above mentioned one electron electrode process at lower gravitational potential can also be formulated as [2,10],

\[ E_l = -\Delta G_l / nF \]  \hspace{1cm} (12)

Since free energy is lower at lower gravitational field i.e. \( \Delta G_l = \xi \Delta G_h \) [9]. So this formulates that electrode potential to be smaller at lower gravitational field i.e.

\[ E_l = \xi E_h \]  \hspace{1cm} (13)

Rate constants of forward and backward reaction can be formulated in terms of Arrhenius factor and free energy of activation as, [11-12]

\[ (k_f)_l = (A_f)_l \exp \left( -\left( \Delta G_{0a}^+ \right)_l / R_l T \right) \exp \left[ -\alpha (E_l - E_l^0 / R_l T) \right] \]  \hspace{1cm} (14)

\[ (k_b)_l = (A_b)_l \exp \left( -\left( \Delta G_{0b}^+ \right)_l / R_h T \right) \exp \left[ (1 - \alpha) (E_h - E_h^0 / R_h T) \right] \]  \hspace{1cm} (15)

For a special case \( E_l = E_l^0 \) rate constant for forward and backward reaction become equal i.e.

\[ (k_0)_l = (A_0)_l \exp \left( -\left( \Delta G_{0a}^+ \right)_l / R_l T \right) = (A_f)_l \exp \left( -\left( \Delta G_{0a}^+ \right)_l / R_l T \right) \]  \hspace{1cm} (16)

On substitution of the gravitational transformation of Arrhenius factor, ideal gas constant and free activation energy in Eq. (16) gives the same gravitational transformation of threshold rate constant i.e.\( (k_0)_l = \xi (k_0)_h \)

Eqs (14) and (15) can be written in more compact form as, [1-2]

\[ (k_f)_l = (k_0)_l \exp \left( -\left( \Delta G_{0a}^+ \right)_l / R_l T \right) \]  \hspace{1cm} (17)

\[ (k_b)_l = (k_0)_l \exp \left[ (1 - \alpha) (E_l - E_l^0 / R_l T) \right] \]  \hspace{1cm} (18)

On substitution of gravitational transformation of electrode potential, ideal gas constant and threshold rate constant in Eqs (17) and (18) gives the same gravitational transformation of rate constant as formulated earlier [9],

\[ (k_f)_l = \xi (k_f)_h \]  \hspace{1cm} (19)

\[ (k_b)_l = \xi (k_b)_h \]  \hspace{1cm} (20)

Butler-Volmer relation that explains total current flow in an electrode process at the lower gravitational field can be stated as [11],

\[ i_l = NFA (k_0)_l \left[ \exp \left( -\alpha (E_l - E_l^0 / R_l T) \right) - \exp \left[ (1 - \alpha) (E_l - E_l^0 / R_l T) \right] \right] \]  \hspace{1cm} (21)

On substitution of the gravitational transformation of electrode potential, ideal gas constant and threshold rate constant in Eq. (21) gives the gravitational transformation of current as,

\[ i_l = \xi i_h \]  \hspace{1cm} (22)
So due to decrease in electric potential at the lower gravitational field, an observer at the lower gravitational field will find net charge transfer per unit time smaller than compared to an observer at the higher gravitational potential this is because of the slower ticking of clocks at the lower gravitational field than at higher gravitational field.

Discussion

Migration of ions towards their respective electrodes is due to the electrostatic force of attraction between the electrode and electrolyte. Potential applied externally on the electrode or potential developed on the electrode when it comes in contact with the electrolyte makes it either positively or negatively charged which attract the ions of opposite charge towards itself to go under respective redox reaction. Now according to Eq. (2) when cell potential will be observed to decrease for moving observer then it means the electrostatic force of attraction between ions and electrode will fall in magnitude for moving observer. To explain this fact we have to take into account some concepts from particle physics [13]. For every force existing in nature, there is a particle that mediates corresponding natural force [14]. For the electrostatic force of attraction, this messenger particle is the photon which is a boson with spin 1 [15-16]. A decrease in potential for moving observer can be explained in terms of interconversion of virtual photons into gravitons. For the gravitational force of attraction, messenger particle is a spin 2-boson named as graviton which can escape into any of the possible higher dimensions [17-18]. Gravitation is explained as a weak force by the unique feature of gravitons i.e. they possess closed strings resulting in leakage of gravitons from the brane into higher-dimensional space [19-20]. Escaping of gravitons into any of higher 4+n dimensions is now a well known and well established theoretical concept very commonly found in the literature [21-23]. D. Boccaletti and et al. have explained the production of gravitons from either fusion of photons in presence of either gravitational field or electromagnetic field [24-25]. While production of gravitons during photon-photon, electron-photon and nucleus-nucleus collisions at the TeV scale has already been predicted many times in literature [26-28].Potential present between electrode and ions is responsible for electrostatic force attracting ions towards the electrode. In moving frame decrease in potential will result in a decrease in the magnitude of electromotive force existing between ions and electrode. For moving observer drop in potential and weakening of electromotive force between ions and electrode occurs because of interconversion of virtual photons (mediating electromotive force between ions and electrode) into gravitons. Potential drop for moving observer at any temperature results from the fusion of virtual photons leading to graviton production which eventually escape into any of possible higher 4+n dimensions. Two virtual photons add up to give a graviton which escapes into higher dimensions. In the present theory, for the first time, it is postulated that for moving observer at any energy scale and temperature two spin-1 bosons “photons” can add up to produce a spin 2-boson “graviton” which disappears into any of possible higher 4+n dimensions. This interconversion of photons into gravitons would result in a decrease in the potential of cell and electrode for moving observer. So for moving observer some of the photons mediating electrostatic force of attraction between ions and electrode will add up to produce a graviton which is a spin 2-boson which would escape into any of possible higher 4+n dimensions thus leading to Lorentz transformation of cell and electrode potential for moving observer i.e. \( (E_{cell/elect})_u = \gamma^{-1}(E_{cell/elect})_0 \). Gravitational transformation of cell potential shown in Eq. (13) reveals that at lower gravitational field electrostatic force of attraction between ions and electrode will decrease in magnitude resulting in a drop of cell potential. Similarly, this decrease in cell potential at the lower gravitational field can be explained in terms of the larger flux of gravitons.
escaping into any of the possible higher dimensions at the lower gravitational field than the flux of gravitons escaping into higher dimensions at higher gravitational field analogous to Lorentz transformation of cell potential. The larger flux of gravitons escaping to higher dimensions at the lower gravitational field as compared to the higher gravitational field can be explained in terms of greater interaction of elementary particles with Higgs field at the lower gravitational field as compared to their interaction with Higgs field at the higher gravitational field. Atoms and molecules are made up of elementary particles which gain mass due to their interaction with Higgs field [29-31]. In lower gravitational field elementary particles interact more strongly with fields gaining more mass at the lower gravitational field than at higher gravitational field i.e., \( m_l = \xi^{-1}m_h \) [9]. This gravitational transformation of mass can also be explained in terms of addition of virtual photons adding up to give gravitons which eventually escape into higher dimensions. Atoms and molecules are composed of positively charged protons residing in the nuclei and negatively charged electrons surrounding the nuclei. There exist two forces between revolving electrons and protons residing nucleus; first force is the electrostatic force of attraction which is due to their charges, and it is governed by the exchange of virtual photons between them [14] while second force is the gravitational force which is due to their masses, and it is governed by the exchange of gravitons between them [21]. At lower gravitational field some of the virtual photons add up to give gravitons that eventually escape into higher dimensions while at higher gravitational field gravitons escaping into higher dimensions is less than at lower gravitational field. This results in a greater flux of gravitons escaping into higher dimensions at the lower gravitational field than the flux of gravitons escaping into higher dimensions at the higher gravitational field. Increase in the number of escaping gravitons at lower gravitational fields leads the particles to interact more intensely with the Higgs Field thus gaining more mass at the lower gravitational field than at higher gravitational field i.e. \( m_l = \xi m_h \). Increase in the number of gravitons escaping into higher dimensions at the lower gravitational field is due to the fusion of virtual photons which mediate the electrostatic force of attraction between electrons and protons of atoms and molecules thus weakens the electrostatic force of attraction. Similarly, virtual photons mediating electrostatic force of attraction between the electrode and electrolyte decreases at the lower gravitational field because some of the virtual photons add up to give gravitons that eventually escape into higher dimensions. So some of the photons mediating electrostatic force of attraction between ions and electrode will add up to produce a graviton which would escape into any of possible higher 4+n dimensions thus weakening the electrostatic force of attraction between the electrode and electrolyte resulting in the gravitational transformation of cell and electrode potential i.e. \( E_l = \xi E_h \).

**Application**

**Daniel cell**

Daniel cell is one of the earliest electro voltaic cells in which Zn(0) is oxidized to Zn(II) at the anode, Cu(II) is reduced to Cu(0) at the cathode, i.e. \( \text{Zn} + \text{Cu}^{2+} \rightarrow \text{Zn}^{2+} + \text{Cu} \) [10]. To demonstrate the quantitative effect of the relativistic time dilation consider the moving observer monitors cell potential at speed of \( 2 \times 10^8 \text{ms}^{-1} \) then cell potential will be observed to decrease as shown in Table 1.
Now to demonstrate the quantitative effect of the gravitational time dilation, consider Daniel cell at two different positions in earth’s gravitational field provided temperature and pressure to be same at two positions. Effect of gravity on rate constant of this gas phase reaction is elaborated in Table 1.

**Table 1.** Comparison of cell potential for moving and stationary observer at 298 K

| Net cell potential for stationary observer (V) | Net cell potential for moving observer (V) |
|----------------------------------------------|-------------------------------------------|
| 1.10                                         | 0.819[a]                                  |

[a] This value has been developed from Eq. (2)

Table 2. Comparison cell potentials at two different positions in earth’s gravitational field provided temperature and pressure to be same i.e. 298 K and 1 atm at both positions

| Net cell potential at surface of earth (V) | Net cell potential at height of 20200km (V) |
|-------------------------------------------|-------------------------------------------|
| 1.10                                      | 1.100000019[b]                            |

[b] This value has been developed from Eq. (13)

**Conclusion**

Lorentz transformation of cell potential results in slower rates of forward and backward redox reactions. Thus moving observer will also find the net current flow to be smaller. In moving frame drop in potential will demand longer time to drive the same charge like that in the rest frame of reference; this is totally in agreement with relativistic time dilation which explains slower ticking of clocks for moving observer. The decrease in cell potential for moving observer is due to decrease in electromotive force operating between ions and electrodes. This decrease in the magnitude of electromotive force and cell potential can be theoretically explained by fusion of two spin-1 bosons i.e. virtual photons producing spin 2-boson graviton which escape in any of possible 4+n extra dimensions. Gravitational transformation of cell potential also results in slower rates of forward and backward redox reactions. The observer at the lower gravitational field will find the net current flow to be smaller in magnitude than an observer at the higher gravitational field; this is because at lower gravitational field drop in potential will demand longer time to drive the same charge as compared to the higher gravitational field. The decrease in the magnitude of cell potential at lower gravitational field results from the fusion of two spin-1 bosons i.e. virtual photons producing spin 2-boson graviton which escape in any of possible 4+n extra dimensions. This results in gravitational time dilation in electrode processes.

**DATA AVAILABILITY**

The data that support the findings of this study are openly available in reference number 10
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