**SUPPLEMENTARY MATERIAL**

**FOR**

**“There are Laws, ….. and There are Laws**

***Law of Mass Action and Conservation of Charge”***

Bob Eisenberg

Department of Molecular Biophysics and Physiology

Rush University Medical Center

Chicago IL 60612

USA

*December 20, 2014*

**Size of discontinuity of current flow.** The reader may hope that the amount of charge involved is too small to matter, but he/she can easily show that not to be the case. The difference in current shown in eq. is the discontinuity of current, the violation of Kirchoff’s law of continuity of current flow.



We can estimate the significance of the error by considering reduced cases.

If all **concentrations are set equal to one**,



If we also set all **charges equal to one**, along with **concentrations equal to one**,



So in this special case, the difference in rate constants determines the imbalance of current, the violation of Kirchoff’s current law.

Alternatively, we can set all **rate constants** and all **concentrations equal to one**,



**Asymmetry of parameters produces discontinuity of current**, and thus violates conservation of charge. If charges flow for one second, the charge imbalance is of the order of , **a huge amount of charge, about 1 coulomb!**

To estimate the effect on electrical potential *V,* we need to know the size of the system. Imagine a spherical capacitor of radius *R.* Its capacitance is  or numerically  where  is the relative dielectric coefficient, about 80 in water solutions at longish times (say > 10-5 sec). One coulomb of charge produces a voltage in this spherical capacitor of  in volts, i.e., a 1 nm capacitor of  produces nearly  volts, i.e., about 1017 volts for a dielectric coefficient of 100. A capacitor of 1 meter radius with —capacitance 111 picofarads—produces nearly 1010 volts.

Of course, these calculations are for current that flows a long period of time (1 second). If current flowed on a biological time scale, for 1 msec in a structure 1 nm in radius, the electrical potential would be much less, ‘only’  volts. Potentials of this size are destructive and incompatible with life or even laboratory experiments.

Molecules and even systems of molecular biology are often some 1-5 nanometer size so small voltages— e.g., **0.2 volts—destroy membranes and membrane proteins**. Membranes breakdown when electrical potentials are 10 million to a billion times smaller than those just calculated. Potentials of this size in fact destroy molecules in general, not just membranes, ionizing them into their constituent atoms. Even atoms are destroyed at these potentials, ionizing into plasmas of electrons and nuclei.

There may be special conditions in which the discontinuity of current flow of eq. may not be important, but in general **the failure of the law of mass action to conserve charge is likely to have noticeable effects.**

NOTES: practical consequences, in models involving multiple pathways of current, flowing in parallel across a membrane limited cell or organelle, Kirchoff’s current law will **itself INDEPENDENT OF MECHANISTIC DETAILS** force correlations of fluxes that have been used to characterize transporters for many years (Hodgkin, 1951).

1. Jaffe, R.L., The Casimir Effect and the Quantum Vacuum*.* Available on <http://arxiv.org/> as <http://arxiv.org/abs/hep-th/0503158>, 2005.

2. Joffe, E.B. and K.-S. Lock, *Grounds for Grounding*. 2010, NY: Wiley-IEEE Press. 1088.

3. Reynaud, S. and A. Lambrecht, Casimir forces*.* 2014. **available on** [**http://arxiv.org/**](http://arxiv.org/) **as** [**http://arxiv.org/abs/1410.2746**](http://arxiv.org/abs/1410.2746).

4. Zangwill, A., *Modern Electrodynamics*. 2013, New York: Cambridge University Press. 977.