**Scientific Laws, Vague, Precise, or even Wrong**

Scientific laws are sometimes vague, sometimes precise. They tend to be landmarks of scientific revolutions, marking new knowledge of the world around and within us, as our measurements get better, along with our ability to analyze their results. Scientific laws are usually learned early in our careers before critical skills are mature, before we learn to referee papers, review grants. It is easy to uncritically use scientific laws that are outmoded or even wrong.

I write to discuss two scientific laws, conservation of charge, and conservation of mass. Both seem precise laws of science, not limited landmarks, and in historical context certainly were. Mass conservation is used in the form of the law of mass action in nearly all of biochemistry to describe chemical reactions and binding in biological systems. Biological systems are always embedded in ionic solutions, and nearly always involve chemical reactants and enzymes with electrical charge. But when mass conservation is applied to charged molecules in chemical reactions, it is easy to show that conservation of charge is not obeyed. I argue that the law of mass action must be extended before it can deal with charge and interactions. The law of mass action was developed with perfect gases in mind, in which infinitely dilute uncharged atoms are the chemical reactants.

Biochemical reactions occur in sequence in one dimension in the schemes analyzed by the law of mass action. Conservation of charge implies that the current flowing through these schemes is identical in each reaction: the flow of charge is continuous without loss. Interruptions in current flow in one place must be able to interrupt a chemical reaction somewhere else, even if those places are far apart. This is a familiar property of Kirchoff’s current law (the classical name for the statement that the flow of charge is continuous without loss). But chemical reaction schemes nearly always involve local theories of rate constants so flows are independent of flows in other reactions or at other locations. I argue that the law of mass action needs to be extended to include the global properties of the electric field, using appropriately general mathematics, for example, field theories and variational principles.

**Conservation of Charge.** Physicists teach that conservation of charge is universally true, exact from very small to very large scales and very small times to very large times, although its interactions with quantum physics produces phenomena like the Casmir effect not obvious in classical formulations. What is not so clearly stated in most texts is that charge flow in real systems is an abstract idea. It is not simply the physical movement of particles of definite charge.

Consider

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).