Electricity is Different

Bob Eisenberg

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In the language of mathematics

'Current'

$$\mathbf{curl}\left(\mathbf{B}/\mu_0\right) = \mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \quad \Rightarrow \quad \mathbf{div}\left(\mathbf{J} + \varepsilon_0\, \partial \mathbf{E}/\partial t\right) = 0$$

'Current'

Measurable

In the language of physics

(1) **J is defined** from experimental measurements of **B** and $\partial \mathbf{E}/\partial t$.

(2) $\mathbf{J} + \varepsilon_0 \dfrac{\partial \mathbf{E}}{\partial t}$ is conserved exactly, always, everywhere.

'Current'

In the language of science, conservation of current **J** is as universal as Maxwell's equations themselves. Maxwell's equations are universal, valid inside atoms and between stars from times much shorter than those of atomic motion (10^{-16} sec) to years (32×10^{6} sec). Charges everywhere move and interact according to Maxwell's equations including inside atoms. Atoms have charge. Chemical bonds are charges shared between atoms. Electrodynamics are embedded in quantum mechanics as the potential $\boldsymbol{V}$ in Schrödinger's wave equation or Bohm's trajectory equations.

The electric field takes on whatever value is needed to ensure conservation of current. Maxwell's equations enforce the conservation of current universally. Properties of matter can change dramatically as the electric field changes, making sparks of plasma in insulators, for example, if dielectric breakdown of atoms, ionization, and sparks are needed to conserve current.

Equations of electrodynamics find little place in the literature of material physics, chemistry, or biochemistry. Widely used kinetic models of chemistry and Markov models in chemistry and biology do not satisfy conservation of current unless modified significantly. They are ordinary differential equations in time and cannot easily adapt to conditions that vary in space.

Fluctuating currents — $\boldsymbol{J}(t;x,y,z)$ such that $\left\langle \boldsymbol{J}(t;x,y,z)\right\rangle = 0$ — produced by thermal variations in potential are significant even in systems at equilibrium with zero macroscopic flow. Fluctuating currents are conserved aby Maxwell equations and so are not local. Nonlocal fluctuating currents are likely to create important effects in equilibrium systems even though the effects are not yet well known. 'Everything interacts with everything else' in electrical systems.

Electricity is different.

*This material is presented in detail in **arXiv ref 1607.06691** and **1609.09175**. The flow of current is described in concrete terms with examples near Fig. 2 in **arXiv ref 1502.07251**, published in the Hungarian Journal of Industry and Chemistry (2016) 44: 1-28.*