Electricity is Different

Bob Eisenberg
August 10, 2016

In mathspeak:

$$\mathbf{curl}\left(\mathbf{B}/\mu_0\right)=\underbrace{\mathbf{J}+\varepsilon_0\frac{\partial\mathbf{E}}{\partial t}}_{\text{'Current'}}\quad\Rightarrow\quad\mathbf{div}\Big(\underbrace{\mathbf{J}+\varepsilon_0\,\partial\mathbf{E}/\partial t}_{\text{'Current'}}\Big)=0$$

$$\underbrace{\mathbf{J}+\varepsilon_0\frac{\partial\mathbf{E}}{\partial t}}_{\text{'Current'}}\ \text{is conserved exactly, always, everywhere.}$$

In words,

Charges are everywhere because most atoms are charged. Chemical bonds are formed by electrons with their charge. Charges move and interact according to Maxwell's equations in space and in atoms where the equations of electrodynamics are embedded in Schrödinger's equation as the potential. Maxwell's equations are universal, valid inside atoms and between stars from times much shorter than those of atomic motion (0.1 femtoseconds) to years (32 mega-seconds).

Maxwell's equations enforce the conservation of current. Analysis shows that the electric field can take on whatever value is needed to ensure conservation of current.

Properties of matter rearrange themselves to satisfy Maxwell's equations and conservation of current. Conservation of current is as universal as Maxwell's equations themselves.

Equations of electrodynamics find little place in the literature of material physics, chemistry, or biochemistry. Kinetic models of chemistry and Markov treatments of atomic motion are ordinary differential equations in time and do not satisfy conservation of current unless modified significantly. Systems at equilibrium, without macroscopic flow, have thermal fluctuating currents that are conserved according to the Maxwell equations although their macroscopic averages are zero. The macroscopic consequences of atomic scale fluctuating thermal currents are not known but are likely to be substantial because of the nonlinear interactions in systems like these, in which 'everything interacts with everything else'.

The material in this lecture is presented in detail in **arXiv ref 1607.06692016**. I recommend having a copy in sight (in hand or in computer).

An extended discussion is found in **arXiv ref 1502.0725**, which has been published as *Mass Action and Conservation of Current*, Hungarian Journal of Industry and Chemistry (2016), 44: 1-28. The extended discussion beginning on p.6 of Fig. 2 is likely to be useful.