

15. The Advent of the Electron.

- 1889. Lodge assesses Maxwell's theory.
 - An excellent account of purely field phenomena, but says little about the interaction between fields and matter.
 - A theory of one medium:

"...it drew no real distinction between ether and matter and treated material bodies simply as portions of the ether in which the electric and magnetic constants (the conductivity, permittivity, and permeability) took on different values." (Hunt, pg. 207.)



"...a sort of skeleton-framework".
Not complete until it is made a
"molecular theory as well". (1893)

"In dealing with the phenomena of electromagnetism we may consider ether and matter as all one medium with different properties in its different parts, some parts being insulating and some conducting, some having one permeability and some another. In such a treatment it is not necessary to look for an explanation of these properties... It is the method employed in our ordinary treatise on electromagnetism and is quite sufficient for most purposes. But just as dealing with light as propagated in rays is a most useful method in optics, but breaks down when we study the subject more profoundly, so we are driven by many electro-chemical phenomena, by the electric discharges in vacuum tubes, and by a number of other phenomena in which the relation of molecules and atoms of matter to the ether is involved, to form some more definite hypothesis as to the connexion of ether and matter than the simple one that we are dealing with -- a single continuous medium with different properties in different parts."



A. *Larmor and the Rotational Ether*

- 1885. Larmor appointed to mathematics lectureship at Cambridge.
 - *1903. Appointed to Lucasian Professor of Mathematics.*
- Dec. 1893. Presents paper "Dynamical Theory of the Electric and Luminiferous Medium" to Royal Society.
 - *Reassessment of MacCullagh's rotationally elastic ether.*



Joseph Larmor
(1857-1942)

Recall:

- 1849. Rankine suggests heat consists of rotational motion of molecular vortices.
- 1856. Thomson suggests magnetism is the alignment of Rankine's vortices, with angular momentum determining their magnetic moment.
- 1878. FitzGerald suggests magnetic force \mathbf{H} and electric displacement $\epsilon\mathbf{E} = \mathbf{D}$ are flow $d\mathbf{R}/dt$ and twist $\nabla \times \mathbf{R}$ of MacCullagh's ether (\mathbf{R} = spatial displacement).
 - *MacCullagh's rotationally elastic ether: resists rotations but not translations.*
- 1885. FitzGerald suggests "vortex sponge" model of the ether: the ether as a tangle of vortex filaments with matter as closed vortex rings.
- 1889. Thomson shows FitzGerald's model is unstable and can't support waves or exert forces.

- Larmor to Lodge:



"I can correlate most things in one scheme if I am allowed that magnetic force is velocity of the aether. Atoms are then vortex rings, and the strength of the rings is their magnetic moment."

Problem #1: Permanent vortices seem impossible.

- Circulation of ether flow around a vortex is nonzero:

$$\nabla \times d\mathbf{R}/dt = \nabla \times \mathbf{H} \neq 0.$$

- So: Every section of a vortex has a displacement current $\nabla \times \mathbf{H} = d\mathbf{D}/dt$.
- So: State of the medium can't be stationary.

- Larmor's solution: The core of a vortex must either be vacuous (hollow) or deprived of elasticity (a "fault" in the medium).
- And: Such vortices can then be thought of as Amperian current loops.

Problem #2: Electric charge seems impossible.

- Suppose ether displacement \mathbf{R} is *uniquely* defined at every point of a dielectric that takes up a volume V .
- Then: The total charge in V is given by ($\rho =$ charge density):

$$\int_V \rho dV = \int_V \nabla \cdot \mathbf{D} dV = \int_V \nabla \cdot (\nabla \times \mathbf{R}) dV = 0.$$

- Larmor's "Maxwellian" solution:



"The legitimate inference is that the electric displacement [\mathbf{D}] in the medium which corresponds to an actual charge cannot be set without some kind of discontinuity or slip in the linear displacement [\mathbf{R}] of the medium; nor can it lose a charge without a similar rupture."

- "This way of thinking was in harmony with Maxwell's view, according to which a conductor could not sustain electric displacement, and the charging or discharging of the conductor required a conducting path, that is, a breakdown of the elastic property of the surrounding dielectric." (Darrigol, 1994, pg. 308.)

- So: Can account for displacement and conduction currents.
 - "A macroscopic vortex implied closed lines of flow, to be identified with the closed lines of magnetic force around a current. As long as this circular flow was resisted by the rotational elasticity of the medium, the vortex corresponded to a displacement current. When the core of the vortex lost its elasticity, a conduction current was held to occur." (Darrigol 2000, pg. 337.)

Problem #3: The strength of a vortex is constant (Helmholtz 1858).

- So: All closed currents in Larmor's theory should be constant.
- Note: This is okay for Amperean microscopic currents in magnets.
- But: How can variable macroscopic currents be explained?

- Larmor's solution:



"Ordinary currents must... be held to flow in incomplete circuits, and to be completed either by conduction across an electrolyte or by electric displacement or discharge across the interval between molecules."

- Idea: "The rotational elasticity within gaps enabled the field to grip and alter the current there, thus making induction possible...". (Hunt, pg. 218.)

"Alteration of the strength of a current implies essentially incompleteness of the inelastic circuit round which it travels, and may be produced either by change of displacement across a dielectric portion of the circuit, or through the successive breaches of the effective elasticity of the æther which are involved in electric transmission across an electrolyte, and also probably in transmission through ordinary media which are not ideal perfect conductors. In short, the existence of electrodynamic induction leads to the conclusion that currents of conduction always flow in open circuits; if the circuit were complete, there would be no means available for the medium to get a hold on the current circulating in it. On this view, the Amperean current circulating in a vortex atom is constant throughout all time, and unaffected by electrodynamic induction..."



Problem #4: Thomson's Objection ("Kelvin's Paradox"):

- Two parallel vortices with the same sign *repel* each other, while the corresponding currents *attract* each other.
- So: Vortices can't correspond to current loops.

● Larmor's response:

- Macroscopic currents always have gaps, and the elasticity of the medium in such gaps allows the field to grip and alter the current, which perhaps can account for the sign difference.
- For closed microscopic Amperean currents, if the vortex cores are hollow, Thomson's derivation doesn't go through.

○ "The complexity and opacity of these arguments turned Larmor's theory into a baroque monster." (Darrigol 1994, pg. 312.)

○ "[Larmor's response to Thomson]... replaced a contradiction with a mystery." (Buchwald 1985, pg. 158.)

B. *Inventing Electrons*

- Spring, summer 1894. FitzGerald chosen as referee for Larmor's paper.
 - Prods Larmor to put something in his vortices for the field to grab onto.
 - "Only in this way, he had argued, could the Amperean current loops be opened up and Kelvin's paradox finally be overcome." (Hunt, pg. 219.)



"What is required in order to obtain a decisive positive result is, that the assumption of a purely cyclic character for the motions associated with permanent magnets shall be avoided by giving the elasticity of the medium some kind of grip on them."

"One way of bringing about this desired interaction of magnetic with elastic energy, at the same time safeguarding the permanence of the atomic current, would be to make it a current of convection, *i.e.* to suppose the core of the vortex-ring to be made up of discrete electric nuclei or centres of radial twist in the medium."



"The monad elements out of which a magnetic molecule of this kind is built up are electric centres or nuclei of radial rotational strain. From what is known of molecular magnitudes, in connexion with electrochemical data, it would appear that to produce an intensity of magnetization of 1700 c.g.s. which is about the limit attainable for iron, these monad charges -- or *electrons*, as we may call them, after Dr. Johnstone Stoney -- must circulate very rapidly, in fact with velocities not many hundred times smaller than the velocity of radiation."

- *Electron* = center of intrinsic radial twist in the ether.
 - "They could be mentally constructed by the kind of ether surgery earlier practiced for the charge of a conductor: remove a filament of the medium ending at the position of the future electron; rotate the walls of the resulting cylindrical cavity; refill the cavity homogeneously." (Darrigol 1994, pg. 313.)
- Rotating chains of electrons replace vortices.
 - *Re-establishes correct sign for microscopic Amperean current interactions.*
- All conduction currents consist of convection currents of electrons.
 - *No need for "breaches" in electric circuits to explain variable macroscopic currents.*

○ "Conductivity in the Maxwellian sense simply dropped out of his theory, as he now traced the flow of ordinary currents and the dissipation of their energy entirely to the motions and collisions of electrons. Similarly, he began to treat displacement in material dielectrics as a real polarization of molecules by the separation of the positive and negative electrons within them." (Hunt, pg. 219.)



- 1895. Lorentz's *Versuch einer Theorie der electrischen und optischen Erscheinungen in bewegten Korpern*.
 - "Unlike Larmor, Lorentz did not try to explain electrons as structures in the ether but simply posited the existence of tiny charged particles within material bodies." (Hunt, pg. 222.)
- But: Both Lorentz and Larmor still accept existence of the ether.



"...it would be possible to ignore the existence of an aether altogether, and simply hold that actions are propagated in time and space from one molecule of matter to the surrounding ones in accordance with the system of mathematical equations which are usually associated with that medium... [But] the idea of an aethereal medium supplies so overwhelmingly natural and powerful an analogy as for purposes of practical reason to demonstrate the existence of the aether."

- Larmor's explanation of the Michelson-Morely experiment:
 - *Lorentz-FitzGerald contraction is a simple consequence of the fact that all matter is made of singularities (electrons) in the ether!*

C. *Assimilating Electrons*

- "Like most British physicists of their generation, FitzGerald and Lodge regarded the advent of the electron not as a threat to their view of the ether, but as an extension of it." (Hunt, pg. 229.)
- Recall: FitzGerald's vortex sponge model of the ether.
 - *Lines of electric force = vortex filaments twisted into spirals.*
 - 1898. Suggests "a permanent kink in such a spiral, with a change in the 'handedness' of the twist on either side, would correspond to a discrete charge -- an electron."



"If we consider a point on a spiral vortex and suppose that the spirality is so arranged that on both sides the flow of fluid within the coils is away from this point, then the spirality on one side of the point must be a right-handed screw, and on the other side a left-handed screw. Now, a point of this kind would be unique in the vortex. It would, so far as the fluid outside the vortex coils was concerned, be a sort of source from which fluid was flowing in all directions... On this hypothesis these vortex spirals would be representatives of the Faraday lines of force. The hypothesis here put forward very tentatively does not include any supposition as to the nature of matter, nor as to how the singular points that represent electric charges, or electrons, can be connected to matter. At the same time it goes some way towards showing that the hypothesis -- that the ether is a turbulent liquid -- has great possibilities underlying it."

- But: Heaviside is less enthusiastic.
 - "Instead of trying to build up electrons from hypothetical vortices in the ether, he simply extended the macroscopic laws of electromagnetism down to the microscopic scale. The field equations always came first for Heaviside; electrons were simply an additional hypothesis to be accommodated by adjusting the boundary conditions." (Hunt, pg. 229.)



"[Lorentz's theory is]... simply Maxwell's theory limited to a particular state of things [with] a lot of electrification moving about..."

- "[Heaviside's reference to electrification] ...reflected his adherence to the strict Maxwellian view of electric charge as merely a surface manifestation of discontinuities in the field, without any independent or substantial existence." (Hunt, pg. 230.)
- Moreover: Electrons break the symmetry of Heaviside's/Maxwell's equations! (No corresponding magnetic monopoles.)

Did the advent of the electron disrupt Maxwellian theory?

- It "...transformed the way charges and currents were conceived, but the Maxwellians had always regarded these as somewhat secondary issues." (Hunt, pg. 238.)
- *The core of Maxwellian theory* = the account of the propagation of waves and energy through the field.



"Now that the doctrine of electricity (at least of negative electricity) as located in small charges or charged bodies is definitely accepted, and now that a current can be treated as the locomotion of actual electricity, it may seem as if some doubt were thrown upon the doctrine, which a little time ago was spoken of as a 'modern view', that the energy of an electric current resides in the space round a conductor. There is no inconsistency, however. The whole of the fields of an electron are outside itself; it is in its fields that its energy resides, and it is in the space round it that energy is conveyed when it moves; for the ether in that space is subject to the co-existence of an electric and a magnetic field." (Lodge, 1906.)

"The electric current is a more material entity, or has a more nearly material aspect, than was thought probable a little while since; but all that was taught about its mode of propulsion, and the diffusion of the propelling force from outside to inside, through successive layers, as it were, of the wire -- all that was taught about the paths by which the energy travels and arrives at point after point of the conductor, these to be dissipated as heat, -- remains true."

