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Background Research Summary

In the early days of electromagnetism, many scientists were working on varied and still disjointed topics, including Oersted, Ampere, Biot, Savart, and Faraday (Arthur, 2013). For example, Faraday proposed that magnetic lines of force (sometimes also called lines of flux) extended everywhere in space (Israelson, 2014). It’s interesting to note the differences between how Faraday thought about these lines compared to how we think of field now. He thought there were many particles in the medium between charges that all exerted forces, thus not fixing “action-at-a-distance,” but limiting the distance to be very small. Gauss thought that electric actions propagate with finite velocity, but did not publish this work, because he couldn’t prove it (Sengupta & Sarkar, 2003). Oersted discovered that a steady electric current will create a magnetic force, and Ampere described this in equation form (Israelson, 2014). Maxwell brought together much of this work.

Most authors characterize Maxwell as picking up from Faraday’s work specifically (Israelson, 2014; Sengupta & Sarkar, 2003; Bork, 1963; Arthur, 2013). Many also agree though that Maxwell synthesized all prior work done by the lengthy list of scientists above (Sengupta & Sarkar, 2003; Arthur, 2013), but more research needs to be done on the ways Maxwell interacted with work by earlier scientists like Gauss, Ampere, etc. Few papers describe this explicitly. Perhaps, this is because there is no record of the explicit references, and Maxwell was instead influenced by these scientists’ work indirectly and did not reference them. There is one implied link in the literature from Gauss’s work to Maxwell’s, though. Riemann was a student of Gauss’s who continued trying after Gauss’s death to prove Gauss’s idea that electric actions propagate with finite velocity (Sengupta & Sarkar, 2003). Maxwell wrote a paper comparing his work to his contemporaries, like Riemann, Weber, and Lorenz (Bork, 1963), so it’s likely he knew of Gauss’s work through Riemann. Clearly, he was influenced in direct and indirect ways.

The first of Maxwell’s three major papers is based directly on Faraday’s idea of magnetic force lines (Bork, 1963). In his second and third (refined from the second) paper, he writes 20 equations describing the electromagnetic field, first termed in his third paper (Bork, 1963; Israelson, 2014). According to Israelson (2014, p. 9), “The specific concepts that Maxwell adopted from Faraday included the field-based definitions of electric charge and current, the concept of conduction as the competition between polarization build-up and decay, and the reduction of all electric and magnetic actions to stresses in the field.” The main concept he adds to the work of those before him is the idea of displacement current. Interestingly, he never makes the explicit argument of the symmetry of equations when including displacement current, despite this being a common modern one (Bork, 1963). Such an argument only comes later in the work of those who refined Maxwell’s equations.

Maxwell’s contemporaries, Boltzmann, Hertz, Kirchoff, Lorenz, and Weber did some work that helped cement Maxwell’s equations (Arthur, 2013). For example, Hertz’s discovery of electromagnetic waves helped Maxwell’s theory gain traction in the scientific world, as it had suggested the existence of electromagnetic waves (Sengupta & Sarkar, 2003). Maxwell’s work was poorly received at first, but picked up traction.

Oliver Heaviside was a major player in bringing about the final form of Maxwell’s equations. He was first to explicitly discuss the symmetry of the equations. In his *Electromagnetic Theory*, he “modifies and extends Maxwell’s equations” (Bork, 1963, p. 5) building on it with rationalized units, vector notation, and symmetry. Heaviside was among several to condense and clarify Maxwell’s equations (Arthur, 2013), some of whom are called the Maxwellians (Sengupta & Sarkar, 2003). Heaviside converted Maxwell’s wieldy quaternions to vector algebra notation, writing div and curl, while Gibbs introduced notation similar to modern notation. Heaviside did not condense the 20 equations but his equations did include four that look similar to the four Maxwell’s equations recognized now. Hertz further clarified the equations (sometimes known as Maxwell-Hertz equations), mostly by removing the potentials and giving them separate forms for free space, conductors, and more (Arthur, 2013).

This brings us to the generally accepted way of writing Maxwell’s equations and explains how Maxwell came to be a pivotal person in the formulation of electromagnetism by synthesizing the work done before him and influencing the work that followed. However, the equations have not remained static, untouched entities since the time of the Maxwellians. There is still a variety of way to express, conceptualize, and prove Maxwell’s equations. An example of one of the many modern ways of thinking about Maxwell’s equations is Feynman’s proof, using only Newton’s laws of motion and commutation relation for position and velocity of a nonrelativistic particle (Dyson, 1990). A more typical modern version of Maxwell’s equations is the tensor form used to express the equations in consistent relativistic language (Griffiths, 2017), credited to Minkowski (Arthur, 2013).

From Griffiths’ footnotes in the last chapter, I’m thinking about reading the following, but I haven’t found the paper yet. Google Scholar said MSU had access, but the link didn’t work, so I’m still looking. Do you have access to it?

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