How the electric telegraph shaped electromagnetism

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The first electric telegraph preceeded the development of electromagnetism and early demonstrations included electrostatic systems consisting of a electrostatic generator effecting the divergence of pith balls at the end of a long wire in 1823. With the discovery of electromagnetic effects by Oersted and the growth of the railways (along which telegraph lines could be laid) 'needle'-based telegraph systems using overhead wires grew in the 1830s and 1840s (ref. 1). These were relatively simple to design and operate, and required little scientific input or rigorous measurement.

The telegraph was important to the colonial project of the Victorian Age as a means to connect the colonies and ensure rapid communication of military, administrative and diplomatic information. J. Henniker Heaton, a member of parliament noted in 1887:

> 'Stronger than death dealing warships, stronger than the might of devoted legions… Stronger than even the unswerving justice of Queen Victoria's rule … are the two or three slender wires that connect the scattered parts of her realm.'[2]

The need for a British controlled international cable network, coupled with the realities of the discontinuities in Her Majesty's realm led to the laying of submarine cables; the first ambitious project being the transatlantic cable which was attempted unsuccessfully in 1858 and succeeded in 1866. The operation of submarine cables posed problems of interest to electromagnetic researchers and also made demands for knowledge on the theoretical community. Through this relationship, electromagnetic research was shaped by the telegraph industry, which played an important role in the development of electromagnetic theory.

Here, I discuss the relationship between the telegraph industry and electromagnetic research under the broad rubrics of the retardation problem, the standards programme and the professionalization of science to establish the importance of the electric telegraph in the development of electromagnetism; challenging the simplistic notion of a one-way relationship between science and technology. In doing so, I shall confront the nature of the causal relationship between science and technology in Victorian England, the prestige gained by science through its contribution to the colonial project and the role of technology and industry in the professionalization of science in the 19th century.

Retardation: the turn to the dielectric

In 1853, Latimer Clark of the Electric Telegraph Company invited Michael Faraday to witness experiments in retardation; the phenomenon of slow propagation and warping of signals in submerged telegraph cables which threatened to slow down the rate of communication. He demonstrated that a 110 mile long gutta-percha (a rubber-like insulator) coated wire submerged in the Thames took up a large charge on being connected to a battery, and that a current could be detected when it was disconnected from the battery and grounded through a galvanometer. Faraday saw the experiments as a strong confirmation of his own 16-year-old theory about the relationship between induction, conduction and insulation[3].

The mathematical modelling of submarine cable telegraphy was taken up by William Thomson (later Lord Kelvin), who calculated the inductive capacity of the gutta-percha-covered cylindrical capacitor as a function of the specific inductive capacity of the insulation and its inner and outer radii. He also formulated an equation for the speed of propagation of signals in a telegraph wire based on his model; a relationship which was important in the eventual success of the transatlantic cable[4].

The phenomenon, of course, was due to the 'capacitor' formed in the insulation between the wire and the water. However, in the 1850s, the idea that dielectrics responded to electromagnetic effects or that there was a displacement current through capacitative arrangements, both fundamental to a 'field theory', was widely dismissed. Electromagnetic phenomena had so far mostly been explained by 'action at a distance (AAD)' theories analogous to gravity, rather than field theories. In bringing out the idea that the propagation of electrical action in conductors was dependent on the surrounding dielectric medium, the retardation problem in cable telegraphy lent credibility to field theories of electromagnetism among British physicists, who had widely dismissed the idea of a specific inductive capacity when it was put forward by Faraday in 1842 (ref. 3). It must, however, be noted that Thomson saw the role of 'inductive capacitance' as merely one of holding the charge on the wire, analogous with heat conduction through an insulated rod. In not recognizing a response in the dielectric medium, Thomson's formulation of the retardation problem saw no need for a theory of propagation of electric effects through dielectrics; he saw the differences between Faraday's vague speculations on the field and Coulomb's action at a distance theory as arising solely from methods of stating and interpretation[4].

Whereas the dominant theoretical model of the retardation problem was in the old tradition of AAD theories, the problem played an significant role in turning the attention of theoreticians to the phenomenon occurring in the dielectric medium outside of conductors and its role in the mediation of electromagnetic effects. As Heaviside noted, Thomson's theory was 'the first step towards getting out of the conductor and into the dielectric'[3]. In his diaries, Thomson had explicitly attacked Faraday's concept of specific inductive capacity in 1842 possibly stemming from the latter's usual lack of rigorous mathematical analysis[4]; his engagement with the retardation problem brought about a willingness to re-engage with Faraday's ideas. The entry of the time derivative in Thomson's model must also be seen as an important conceptual development in electromagnetic theory brought about by cable telegraphy, as it recognized the need for a theory of propagation of electrical effects through conductors, if not through dielectrics.

Stokes viewed the problem as one of a longitudinal resistance (the copper wire) flanked by a lateral capacitor (the insulation), with the circuit through the capacitor being closed through conduction in the water. He mentioned the time required to produce a 'change in the molecular state of the dielectric gutta-percha' as a possible cause for the retardation, but set the idea aside as 'altogether hypothetical'. This speculation was conceptually almost identical to that of a 'displacement current' through the dielectric that would make Maxwell famous[4]. Stokes speculation indicates that the retardation problem led to an interest among theoreticians in reinterpreting Faraday's experiments and to an amenability to theories of the field.

The engagement with the retardation problem was in a greater Victorian tradition of a utilitarian science which looked upon machines as natural bodies for the furnishing of data and as examples for illustrating principles[4], which was also exemplified in the development of thermodynamics. Thomson used data of retardation times to calculate within a factor of two the ratio of electromagnetic and electrostatic units, seeing it as a beautiful way of calculating the value[3]. This ratio was to be central to Maxwell's work as being equal to the speed of light, though Thomson did not conceive it as such. Faraday himself noted the new insights that were to be gained from studying telegraphy problems, saying: 'When the discoveries of philosophers and their results are put into practice, new facts and new results are daily elicited'[3].

It is in the demonstration of the utility of theoretical science that primary importance of the retardation problem to the development of electromagnetism lies. The eventual success of the transatlantic cable was seen to be in great measure a result of Thomson's work (as in practice AAD theories can explain most electromagnetic phenomena as well as field theory, as is well known) and lent a new prestige to the science. As Clark noted in 1860, 'Faraday's interesting researches … [were] a consideration of high national importance … which has a direct and most important bearing on the commercial value of all submarine telegraphs'[3].

The episode also began a long engagement of researchers with the telegraph industry, which was to be important for the future development of electromagnetism.

Quantification: units and measurements

The inquiry into the failure of the first transatlantic cable recommended the standardized precision measurement of quantities, particularly standardization of resistance coils[4]. The industry had been using an arbitrary length of a mercury column proposed by Siemens as a standard resistance for fault detection. The British Association for the Advancement of Science set up a Committee to device a system of absolute units and measurements for the telegraph industry[5]. It must be noted that for much of the 19th century, electromagnetic researchers had little conception of units; it is amusing to read the words 'intensity' (for potential) and quantity (for charge), in scientific works from the period. Ohm's law originally stated that the restoring torque on a magnetized needle (a measure of the current) was inversely proportional to the length of the conductor (a measure of the resistance). The British Association Committee emphasized the need for an absolute system of units not based on any arbitrary measure:

> 'Instead of a simple comparison with an arbitrary quantity … the word absolute is intended to convey the natural connexion between one kind of magnitude and another … and that all the units form part of a coherent system … [whose] use will lead … to a general knowledge of these relations.'[4]

The specific aim of the Committee was to determine the most convenient unit of resistance, as a base to determining other units. The electromagnetic system of units (emu) was more useful to the telegraphy industry. Unlike the electrostatic (esu) system, which measured the force between two point charges as the starting point, it used current as determined from electromagnetic effects for the same. The project was essentially to calculate the standard ohm (having the dimensions of velocity in the emu system); defined as the velocity of a conductor of unit length that must move across a magnetic field of unit intensity so as to generate a unit current in the said resistance of the conductor. The system was anchored around the new concept of work–energy equivalence, replacing Coulomb's law with Joule's law as one of the fundamental relationships of the system[4]. Energy was the unifying concept of the new physics which developed in the 19th century[6]. The replacement of an action at a distance law with a law based on the new energy concept was a move towards the unification of electromagnetic theory within the framework of other theories of 19th century physics.

In choosing the electromagnetic system of units, the Committee also raised the question of measuring the esu/emu ratio, which was to be fundamental to the Maxwellian link between optical and electromagnetic phenomena. The sixth report of the Committee (1869) set out the experiments of Maxwell and Thomson in the direction[4]. This push towards the determination of the ratio was the first institutionalized effort in the direction. Maxwell reworked the standards project as part of his electromagnetic physics, making a purely scientific problem seem commercially consequential[5]. Working on the standards programme, Maxwell managed to calculate the ratio to within 10% of the speed of light[5].

The standards were institutionalized at an International Conference in 1881. The standards programme put at the disposal of physicists a vast experimental infrastructure. As Maxwell wrote in 1873:

> 'The important applications of electromagnetism to telegraphy have also reacted on pure science by giving a commercial value to accurate electrical measurements and by affording to electricians the use of apparatus on a scale which greatly transcends that of any ordinary laboratory'[7].

In 1871, Thomson noted the influence of having accurate means of measurement on theory, when he said:

> 'When the assistance of the British Association was invoked to supply their electricians with methods of absolute measurement ... They were laying the foundation for accurate electrical measurement in every scientific laboratory in the world, and initiating a train of investigation which now sends up branches into the loftiest regions and subtlest ether of natural philosophy.'[3]

The units programme was also seen as a means to display the success of British electromagnetic researchers and to liberate cable networks from German industrial control by setting up an absolutely permanent standard and welding it into international telegraphy[5]. The smooth functioning of the British telegraph network around the world was seen as critical for the maintenance of a colonial empire. The British Association standard resistance boxes were sent to and used by telegraphers in India and Australia[4]. In welding the success of the colonial project with the success of electromagnetic researchers, and in demonstrating the utility of the new science to political objectives, the standards programme helped electromagnetism gain a prestige which encouraged its development.

Theory and practice: the shaping of a profession

The inquiry into the failure of the first transatlantic telegraph exposed the weaknesses of purely empirical engineering and pushed for precision measurements, laboratory testing and theoretical design, specifically criticizing the brute force methods of 'practical men' such as the use of high voltages. While chairs in engineering had appeared in British universities beginning in the 1840s, engineers qualified by apprenticeship rather than by academic degrees and 'the scientific engineer, like the research physicist had yet to be born into Britain'[4]. Physical research was not a professional activity; with no technicians in academia, no organized supervision and no way of making a living through research. Experimentalists such as Rayleigh and Stokes were from an upper class background and operated in private laboratories. Teaching at universities such as Cambridge had no component of practical training and the single largest group of successful candidates at the Mathematical Tripos chose to go into the clergy[8]. Most of whom we would describe today as physics researchers were professors of either mathematics or natural philosophy. In fact, even the word 'scientist' was still new, having been coined only in 1833. In this section, I discuss the role played by the telegraph industry in the professionalization of scientific research, and in the integration of experimental activities within academic research and training.

The Cavendish Laboratory was founded in 1871 and the development of a resistance standard for telegraphy was its first project. Maxwell moved to Cambridge to head the Laboratory, occupying the first chair of experimental physics at Cambridge. It brought together theoretical and experimental research at Cambridge; placing demands for students trained in experiments, active researchers, skilled technicians and instrument fabricators. The standards programme was seen as a way to make laboratory research count worldwide; its success lent visibility to the utility of academic research. The Laboratory also operated as a teaching institution, first through 'Experiments of Illustration' and later involving the active participation of students[8]. The pursuit of the standards programme at Cavendish, led to the institutionalization of experimental research and training in an academic setting[5].

Thomson provided research services to the telegraph industry on several occasions, such as in standardizing copper cables. At the Glasgow laboratory, he patented several devices with the telegraph engineer Fleeming Jenkin, such as the quadrant electrometer and the mirror galvanometer; these earned him several thousand pounds. He was also approached by the Submarine Telegraph Works to provide them an 'aspirant philosopher and experimentalist'; all developments which the prioritization of scientific education over practical experience with monetary rewards to those so trained, besides exemplifying the funding of academic research by industry[4]. The new British laboratories of 1860–1880 were part of the Imperial communications project through their work on electromagnetic standards and their training of expert telegraphists. That the success of the transatlantic cable was the result of work at the Glasgow laboratory in the inventions of Thomson and the service of his students in telegraph companies throughout the empire was well recognized at the time[5].

Cable telegraphy revealed the importance of academic research and training to the industry and ultimately to the maintenance of the Empire. Through its role in the integration of experimental and theoretical research, in the institutionalization of practical training within the academic curriculum and in the funding of academic research, the telegraph industry aided the emergence of physical research in general and electromagnetic research in particular, as a viable profession in the late 19th century.

Conclusion

The exploration of the link between the telegraph industry and electromagnetic researchers demonstrates the complexity of the relationship between technology and science; how technology may be important for the development of scientific theory. The development of electromagnetism was shaped not just by the needs of the telegraph industry for instruments and standards, but also by the new phenomenon which was noted in the operation of submarine cables. The telegraph played a crucial role in highlighting the utility of electromagnetic research and in increasing its prestige by linking it to the maintenance of the Empire. This gave the researchers access to a massive experimental infrastructure. It also changed the nature of academic training and research, and made scientific research a viable profession.

The traditional analysis of the relationship between science and colonialism sees it as one of data from the colonies being used by metropolitan science and science in the colonies as a manifestation of the colonial mission. The social history of electromagnetism demonstrates the shaping of science in the metropolis by the aims of the colonial project and the role of colonialism in raising the stature of pure science within the metropolis.

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