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Sir William Thomson:
Explaining a Scientific and Innovative Character at Glasgow University

Bachelor Thesis

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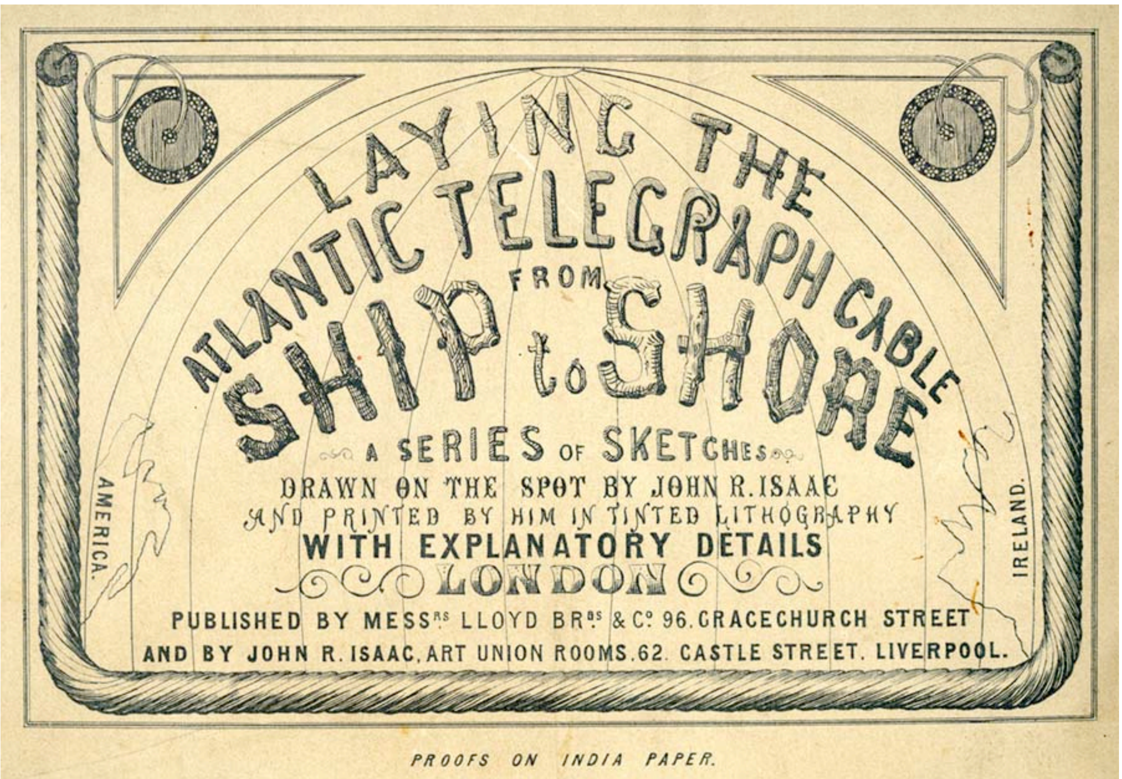

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Sir William Thomson: Explaining a Scientific and Innovative Character at Glasgow University

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Abstract

Sir William Thomson (1824-1907) was a successful scientist and innovator of industry. He wrote over 650 scientific papers and registered over 70 patents. This paper will investigate in what way his two-sided professional character was representative of his academic environment, specifically Glasgow University. His election as the new professor of Natural Philosophy, his establishment of the first physical laboratory and his work on the trans-Atlantic Telegraph will be closely examined. They will offer insight into Thomson's capability to move between science and industry, and the supporting role of Glasgow University. It will become clear that Glasgow University had aligned itself with the industrial city through reforms in the early nineteenth century. Its aim, though, was to serve the industrial class by *teaching* them useful knowledge, not by explicitly offering innovation. It will become clear that Thomson pioneered a new experimental methodology at his laboratory that was based on *precision measurement* and *mathematical* theory. Thomson understood early on that the physical laboratory was the prime vehicle for scientific *and* industrial progress; his successful innovations will essentially turn out to be extensions of his laboratory methods. Thomson was, thus, ahead of his academic environment, though the University's alignment with industry is what truly allowed him to flourish.

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Introduction

"We who live in an age where science is recognized as a means of life or death, cannot fail to see all around us the consequences and even the instruments of science."[1] This remark by the historian John Desmond Bernal already identified science as a pillar of modern society back in 1953. One could reasonably argue that it is even more applicable to us today: the Internet and the exploration of Space owe their existence directly to science. Bernal, furthermore and equally relevant today, remarked that "[this] makes it extremely difficult to disentangle science from the social and economic factors with which it is entwined."[2] A very interesting relation is that between science and industry, because their combined efforts in particular, in the form of technology, shape our daily life significantly. That relation is, however, not straightforward, but really quite intricate. Different questions arise: fundamental science can obviously culminate in useful technology interesting for industry, but can industry conversely shape the direction of fundamental science? Should it? Or is *science for science's sake* the best driving force of scientific progress? Does the work on the Quantum Computer at TU Delft produce less fundamental research than the work at CERN? These questions are relevant to many, including policy-makers, companies and scientists themselves. A way of analysing the relation between science and industry is using a historical approach and asking yourself the question: how did the relation between science and industry manifest itself *in the past*? This has the obvious benefit that we can also include its consequences. Such a historical investigation is precisely what will be conducted in this paper.

The subject of our investigation will be the life of William Thomson (1824-1907), who was the professor of Natural Philosophy at the University of Glasgow for over fifty years. He is an interesting historical subject for a variety of reasons. The main reason is that William Thomson was the *embodiment* of a potent relation between science and industry: on the one hand, he made fundamental contributions to scientific fields like thermodynamics and electrodynamics; on the other hand, he developed a significant amount of successful patents that made him a wealthy man, including novel apparatus for the telegraphy industry. During his productive life he produced more than 650 scientific papers and over 70 patents. His achievements would bring him his knighthood in 1867 – becoming *Sir* William Thomson – and an elevation to the peerage in 1892 – becoming *Lord Kelvin*.[3]

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[1] J.D. Bernal, *Science and Industry in the Nineteenth Century* (London, 1953), p. 3
[2] Ibid.
[3] C.W. Smith and M.N. Wise, *Energy & Empire: A Biographical Study of Lord Kelvin* (Cambridge, 1989);

Another reason to investigate Thomson's life is that it coincided with a particularly interesting period in history. When Thomson was born, the Industrial Revolution had already been going on in Britain for over half a century. The following comment by engineer John Farey in *A Treatise on the Steam Engine* (1827) illustrates that British society was rapidly transforming under the influence of industrialization: "The high state of wealth and civilization which the English people have attained in the last half century, has been greatly promoted by the application of the steam-engine to various purposes of the useful arts, in aid of manual labour."[4] In Thomson's lifetime industry got truly rooted in society through the widespread diffusion of technology: the Grand Exhibition in London in 1851 was the first – immensely popular - demonstration of superior technology; also the successive emergence of the telegraphy, electric light and electric power industries transformed ordinary life. This period is also interesting with regard to, in particular, the history of science: the nineteenth century saw the specialization, professionalization and expansion of different sciences, including the emergence of modern-day physics. The formulation of the Conservation of Energy principle in the 1850's is regarded as a key moment in that process, for it linked several physical subjects through the general concept of *energy*. Another was the broad integration of a modern experimental methodology – matured in the physical laboratories during the 1860's - into the process of theoretical advancement. Thomson had an active part in both.

The final reason that Thomson makes such a resourceful subject is the fact that he was professor at one specific academic institution, the University of Glasgow, for his whole career of more than fifty years. When one desires to investigate the relation between science and industry, such a situation allows for a deeper characterization of the science part. This finally brings the main research question of this paper into focus: *in what way was Sir William Thomson's two-sided character – namely his pure scientific and (commercially) innovative side – representative for his academic environment?*

To be able to proceed sensibly, a proper introduction to this period in the history of science is required. As mentioned before, the main trend in the nineteenth century was the specialization, professionalization and expansion of different sciences. This includes the rise of modern-day physics, which is based on the general concepts of force and energy; described by mathematical theory; and solidified by thorough experimentation. Where did it come from?

Modern-day physics mainly originated from the gradual unification of two former distinct clusters of scientific fields: the *classical* and *Baconian sciences.*[5] The classical sciences found their roots in antiquity and consisted of the subjects Astronomy, Harmonics, Optics, Statics, Motion and Mathematics. Although there were significant *internal* changes, they formed a relatively unified group into the nineteenth century. These subjects were connected, above all, through their common mathematical nature. Newton's

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[4] J. Farey, *A Treatise on the Steam Engine: Historical, Practical, and Descriptive* (London, 1827), p. v

[5] T. Kuhn, "Mathematical vs Experimental Traditions in the Development of Physical Science", *The Journal of Interdisciplinary History*, **1** (1976), p. 11

Philosophiae Naturalis Principia Mathematica (1687) was a true milestone for the use of mathematical theory in, for instance, astronomy. The fact that he also wrote *Opticks* (1704) demonstrates that he easily moved between the different classical subjects. This ease is also seen with others, like Galileo, Descartes, and Kepler. The classical sciences were empirical, but its experimental practice was quite limited, serving two main goals: "to demonstrate a conclusion known in advance by other means"; or "to provide concrete answers to questions posed by existing theory."[6] In other words, new knowledge was gained through *deduction*: experimental results should fit the conclusions deduced from general principles.

In the sixteenth century *Baconian science* emerged as a different sort of empirical science. It was named after its principal leader Francis Bacon (1561-1626) who "was the first of the long line of scientifically minded philosophers who have emphasized *the importance of induction* as opposed to deduction."[7] This meant that general principles could only be inferred from specific premises. As a result its experimental practice tried to be completely unprejudiced, because it "seldom aimed to demonstrate what was already known or to determine a detail required for the extension of existing theory."[8] Its practitioners - men like Gilbert, Boyle and Hooke – preferred experiments that *constrained* nature in ways yet unseen; a whole variety of new instruments were introduced to further this aim. As an important consequence, the new empirical attitude gave rise to novel scientific fields, including magnetism, electricity, the study of heat and chemistry. These Baconian sciences distrusted mathematics, because of its intrinsic deductive structure. So, both in their approach as in their subjects, the *classical* and *Baconian* sciences were strikingly different.

"Physics required, as other sciences did not, the establishment of a firm bridge across the classical-Baconian divide."[9] In a way this bridge was to be expected (never to be confused with inevitability). For one, both clusters were concerned with the study of non-living natural phenomena and should, thus, both fall within the range of *physical science,* or the contemporary subject of Natural Philosophy. Second, the purely inductive method of the Baconian sciences was incomplete through insufficient emphasis on hypothesis: mere systematic ordering of experimental results seldom allows for the effective construction of hypotheses. "As a rule," Bertrand Russell noted, "the framing of hypotheses is the most difficult part of scientific work, and the part where great ability is indispensable." A synthesis of the classical and Baconian experimental methods offers a promising solution: a mathematical approach towards framing hypotheses (and subsequent theory); and a meticulous approach towards experimentation based on falsification of hypotheses.

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[6] T. Kuhn, "Mathematical vs Experimental Traditions in the Development of Physical Science", *The Journal of Interdisciplinary History*, **1** (1976), p. 11

[7] B. Russell, *History of Western Philosophy* (1946); edn. Routledge Classics, 2004; p. 498 (emphasis added by author)

[8] See Kuhn (1976), p.12

[9] Ibid. p. 30

The traditional academic institutions mainly inhibited the establishment of the bridge across classical-Baconian divide. Generally these institutions only treated *classical* sciences. At academic societies, like the French *Academie des Sciences* and the British *Royal Society*, the classical tradition would dominate into the nineteenth century. The traditional medieval Universities, like Cambridge and the Sorbonne, had a strong emphasis on teaching *humaniora*, including *classical* sciences.

The first real steps were made in France halfway the eighteenth century. Several typical Baconian sciences were gradually introduced to academic institutions, especially military engineering schools. These sciences became known as *la physique experimentale*. The main French contribution wasn't, however, in the actual experimentation, but in the trend of *mathematization* they started: armed with novel *analytical* mathematics, as opposed to Newtonian geometric mathematics, the French extended their mathematics to both classical and Baconian fields. Lagrange formulated his mathematics of generalized mechanics, for example, and Laplace his analytical theory of astronomy. It is also in this period that Fourier wrote his *Theorie Analytique de la Chaleur* (1822), which would greatly influence Thomson. The French leadership would endure into the early nineteenth century.

The Germans and British would follow after the early nineteenth century. In Germany the followers of the predominant *Naturphilosophie* were dedicated to understand Nature as a whole. Their appreciation for interconnections between various subjects automatically loosened up the former divisions between classical and Baconian sciences. Another important feature involved the German Universities. Reform of the academic system by von Humboldt in the early nineteenth century enabled the German Universities to embrace - or even create - a new progressive spirit that facilitated changes more easily than their French and English counterparts. This spirit allowed, in particular, the rise of the *research seminars* that "promoted the instruction of pupils through the imparting of a rigorous technique that was first learned by example and then applied, under supervision, to the advancement of knowledge."[10] It was a next step in the synthesis of the classical and Baconian experimental method, because "men like Neumann, Weber, Helmholtz, and Kirchhoff were creating a new discipline in which both experimental and mathematical theorists would be associated as practitioners of *physics*."[11] To promote efficient communication and a collective direction in science in all German states the *Deutscher Naturforscher Versammlung* was established in 1822. This plasticity of German educational institutions and their subsequent integration with State and industry would lead to a German hegemony in science it the end of the nineteenth century.[12]

In Britain at the beginning of the nineteenth century a sense of decline in British science was increasingly experienced among its practitioners. Progressive men like John Herschel, Charles Babbage and William Whewell identified its main cause as the almost dogmatic following of Newtonian

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[10] R. Fox and A. Guagnini, *Laboratories, workshops, and sites: Concepts and practices of research in industrial Europe, 1800-1914* (Berkeley, 1999), p.43

[11] See Kuhn, p.31

[12] See Bernal, p.142-144; and see Kuhn p.31

mathematical physics. They explicitly called for the study of the new French mathematics.[13] The traditional Universities at first inhibited the integration of Baconian sciences into their curriculum. The Scottish Universities, though, were able to make progressive reforms way earlier than their English counterparts. In England a reaction was the creation of novel liberal colleges in London: University College (1826) and King's College (1829). Frustration with the slowly adapting *Royal Society* culminated in the establishment of the *British Association for the Advancement of Science* in 1831, based on the German example. Its aim was to "give a stronger impulse and more systematic direction to scientific inquiry, to obtain a greater degree of national attention to the objects of science, and a removal of those disadvantages which impede its progress, and to promote the intercourse of the cultivators of science with one another, and with foreign philosophers."[14] This Association would play an important role in the direction of British science for the rest of the century. More importantly, it wouldn't hesitate to direct its attention towards industry.

Using the *British Association for the Advancement of Science* it is possible to properly introduce the role of industry. This Association was founded on several radical principles of the Enlightenment: with Reason one could understand - and possibly master - the forces of Nature, ultimately using it for the general benefit of mankind. Hence, science through industry could directly benefit mankind. Secondly, directing science to the enhancement of industry simply makes the British Empire more powerful and wealthier. Especially the former integrated deeply in the Scottish intellectual atmosphere that Thomson was a part of. Elucidating the direct links to industry will remain a main epistemological theme throughout this paper.

Now, William Thomson can be effectively located in this woven fabric of history.

Chapter 1 closely examines the election of William Thomson as the Glasgow professor of Natural Philosophy in 1846. It will identify Thomson's individual qualities, especially those valued by the Glasgow election committee. These are the starting point to further identify the contemporary character of Glasgow University. Was Glasgow University actively establishing a bridge across the classical-Baconian divide? What was the University's link with Glasgow industry? This chapter enables one to understand what made Glasgow University – Thomson's direct academic environment – such a suitable place for Thomson's two-sided character to thrive.

Chapter 2 investigates the establishment of the Glasgow physical laboratory. Thomson extended laboratory methods from chemistry into the realm of Natural Philosophy by establishing the first British *physical* laboratory. The establishment and subsequent development of Thomson's laboratory will be understood as a pioneering step in the synthesis of a novel experimental methodology in Natural Philosophy. From the start its investigations held direct relations with industry in both an explicit and implicit manner. Thomson understood early on that the laboratory was the prime vehicle for scientific and industrial progress. Thomson's own industrial innovations were a direct extension of his work at the laboratory.

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[13] See Smith and Wise, chapter 6

[14] See Bernal, p. 140-141; quoting Babbage from C. Babbage, *Reflections on the Decline of Science and on some of its Causes* (London, 1830), p.16-17

Chapter 3 focuses on Thomson's work on the trans-Atlantic telegraph cable. This work will exemplify Thomson's scientific attitude when engaging with industry. It will illustrate how Thomson employed his novel experimental methodology: mathematical theory to comprehend the problem and precision measurement for proper falsification. The subsequent success put science at the heart of industry.

In the conclusion we return to answer our main question: *in what way was Sir William Thomson's two-sided character – namely his pure scientific and (commercially) innovative side – representative for his academic environment?*

Chapter 1

Electing the Glasgow Professor of Natural Philosophy

In 1846 William Thomson became the Glasgow professor of Natural Philosophy when he was only twenty-two years old. Recent reforms had changed Glasgow University from a conservative and clerical institution into a progressive one that aimed at promoting the diffusion of knowledge to the people. Hence, their primary requirement for the new professor of Natural Philosophy was that he could adequately communicate new knowledge to students; in other words, that he was an excellent teacher.

To meet this requirement, the election committee expected to find two main qualities in a suitable candidate: excellent mathematical skills to effectively communicate the new French style physics; and fine experimental skills to adequately teach the experimental course in Natural Philosophy. It is interesting to note here that Natural Philosophy consisted of a *mathematical* and *experimental* part and, thus, to some extent already treated both *classical* and *Baconian* sciences. Thomson had demonstrated exceptional mathematical talent during his student years at Cambridge, so the election committee had no doubts about the mathematical requirement. However, several members of the election committee strongly advised Thomson to enhance *his limited experimental skills* at the state-of-the-art laboratory of Victor Regnault in Paris.

The University of Glasgow

The University of Glasgow was founded in 1451. Like most Universities that originated during that time their curriculum consisted of the *humaniora* and their student-body was mainly comprised of future clergymen. This would characterize most of these institutions till the early nineteenth century: at Cambridge around 1850 over one third of students were Anglican clergymen and the curriculum still heavily depended on teaching classical literature, philosophy and mathematics. The University of Glasgow was a very conservative institution as well at the beginning of the nineteenth century: most of the professors then were politically conservative (*Tory*) and big supporters of the established Church of Scotland. Effectively, in their eyes the University served the traditional intellectual elites.

Between 1800 and 1840 Glasgow rapidly changed from a commercial town to a bustling industrial city: its population exploded from 77000 to 200000, and its wealth "depended more upon iron, steam, and above all ships and shipbuilding."[15] These industries thrived due to abundant coal nearby and easy access to the sea. Glasgow would even be nicknamed

[15] See Smith and Wise, p.20

the 'Second City of the Empire' for its powerful industry. The industrialization gave rise to a new industrial class in Glasgow – like the shipbuilding family Napier. The conservative professors that held University power, though, had "little in common with the rising industrial city founded on whig [liberal] values."[16] This conservative attitude started to change after the 1830's, eventually leading to gradual alignment with the industrial identity of the city.

An important question is *why this alignment should even happen?* Traditional Universities in England and France inhibited such transformations for decades. The answer is rooted in the characteristic *Scottish* intellectual atmosphere of the time; Scotland was profoundly protestant. According to professor G.E. Davie in his book *The Democratic Intellect*[17], this especially gave rise to popular values in education: the aim of education should be the diffusion of knowledge to the people. These democratic convictions were also gradually found at Glasgow University.

The main leader of reform was James Thomson (William's father), who was elected as the professor of mathematics in 1832. Before, he had been the professor of mathematics at the novel Belfast Academical Institution (1814), where a lot of students had come from the local industrial and mercantile classes. Coming from a humble background, James Thomson had actually achieved social advancement through education himself. He was, hence, a logical spokesman for the ideal of widespread education of the people. Another fierce proponent was the Glasgow professor of Astronomy, John Pringle Nichol, who believed the aim of education was "to draw out man into freedom, and to establish between him and the universe, a solid and practical harmony."[18] This democratic ideal would increasingly spread among other Glasgow professors. Education of the people became the University's primary aim.

Another component of the Scottish intellectual atmosphere was the ideal of the Enlightenment that knowledge leads to the improvement of man's condition. The Glasgow professor of Natural Philosophy, Meikleham, translated this directly into a direct aim of his field: to extend "our power over nature by unfolding the principles of the most useful arts [the employment of means to gain ends]."[19] Essentially, the Scottish tradition of Natural Philosophy explicitly favoured a *harmony between theory and practice*.

This perceived harmony carries the connotation of *utility* and helps to understand why Baconian sciences were integrated more quickly in the curriculum of Natural Philosophy, through the introduction of an *experimental* course: because Baconian sciences had always emphasized *utility*. The whole basis of Francis Bacon's philosophy had been, according to Bertrand Russell, "to give mankind mastery over the forces of nature

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[16] See Smith and Wise (1989), p. 25

[17] G.E. Davie, *The Democratic Intellect: Scotland and her Universities in the Nineteenth Century* (Edinburgh, 1961); see particularly "the Introductory Essay"

[18] See Smith and Wise (1989), p. 39; quoting J.P. Nichol from J.P. Nichol, *Preliminary Dissertation*

[19] Ibid. p. 649

by means of scientific discoveries and inventions."[20] An industrial dimension strengthened the emphasis on utility in Baconian sciences: steam engines and the study of heat were directly related, as were the textile industry and chemistry. An early bridge across the classical-Baconian divide, thus, seemed to have been established, due to the Scottish emphasis on the harmony of theory and practice.

The Scottish democratic ideal of education and perceived harmony between theory and practice offer an explanation for the eventual alignment of the University with the industrial city, but there is an extra reason. The average salary of a Glasgow professor was relatively low, so they depended heavily on student fees for a stable income. A big part of their daily work was to actually *market their knowledge*. James Thomson, as an example, even gave additional astronomy lectures to interested Glasgow women. Above all the required ability to market your knowledge emphasizes again the importance of effective teaching skills.

The contrast with other academic institutions highlights the distinctly Scottish characteristics of Glasgow University. In France Baconian subjects were slowly introduced from the 1760's into the curriculum of, in particular, military engineering schools like the *Ecole du genie de Mezieres*. In the 1790's the novel *Ecole Polytechnique* was established. Besides classical subjects students at this *new type of institution* also learned more experimental subjects, including chemistry and the study of heat. Most influential French men of physical science in this period were connected to the *Ecole Polytechnique*, instead of the traditional scholastic Universities. This fact points out that change came slow at traditional institutions of this highly centralized and *hierarchical* state, but was able to flourish in the military structure where the industrial potential was readily acknowledged by the engineering schools.

In England traditional Universities remained highly elitist: they hardly had students from the industrial class. Maxwell once noted that "the Scots aimed to make general education (organized around philosophy) the foundation for particular technical studies, whereas the English aimed to make particular technical studies (with an emphasis on intellectual discipline) the basis for a general education."[21] Because the basis for a general education was solid, according to influential Cambridge people like Whewell, the integration of new subjects wasn't of the essence. The primary reaction in England was, much like in France, the establishment of novel institutions – several Colleges in London – and the introduction of several Baconian sciences in established engineering schools – such as the Royal Engineering School and the Royal School of Mines. Its appearance seems to suggest a special role for the field of *engineering* in highlighting relations between science and industry.

A professorship of Engineering was established relatively early in the nineteenth century at Glasgow University – in 1840. Engineers were practical men who used to be trained in apprenticeships at industrial companies. With the establishment of an academic chair the relation

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[20] See Russell (1946), p. 498

[21] See Smith and Wise (1989), p. 88

between science and industry is strengthened. From the Scottish perspective on the harmony of theory and practice the establishment makes sense. Though, when we reiterate Natural Philosophy's aim to extend "our power over nature by unfolding the principles of the most useful arts [the employment of means to gain ends]", the difference with engineering becomes unclear. This was actually the case, as the historian Romueldas Sviedrys noted, "boundaries between physics and engineering were still fluid and easily and often crossed."[22] William Thomson would thrive on this Glasgow tension between Engineering and Natural Philosophy.

First, Thomson still had to get elected.

The Election

When the professor of Natural Philosophy at the time, William Meikleham, fell increasingly ill in the early 1840's, the professors at the University of Glasgow had to start their search for a successor. For the reformers this was an important moment to consolidate their steady advance on the conservative forces at the University. The election committee, thus, looked for two main qualities in a suitable candidate: excellent mathematical skills to effectively communicate the new French style physics; and fine experimental skills to adequately teach the experimental course in Natural Philosophy.

The young Thomson had been heavily influenced by his own education. He started his studies at the age of ten at the University of Glasgow, although he officially enrolled at the age of fourteen. He showed an exceptional mathematical talent early on. He wrote price-winning essays about a variety of highly mathematical subjects, including an essay on determining the age of the earth. In the lectures of Natural Philosophy by professor Meikleham he was encouraged to read the new French mathematical works. Meikleham actually introduced to him his life-long inspiration, Fourier's highly mathematical *Theorie Analytique de la Chaleur*. Thomson's mathematical talent was again demonstrated, when he wrote an essay in which he successfully rebuked criticism on Fourier's work by a professor at the University of Edinburgh when he was in his teens.

His contact with the professor of Astronomy, John Pringle Nichol, appears to have been influential as well. He set a great example for the young Thomson as a creative and inspiring teacher. He was also a fervent *democratic* reformer and believed in the harmony between theory and practice. Thomson would later praise Nichol by saying: "His appointment as professor of astronomy conferred benefit, not only upon the University of Glasgow, but also upon the city and upon Edinburgh and the far wider regions of the world, where his lectures were given and his books read."[23] During his studies at the University of Glasgow he was inspired by the power of Pringle's excellent lectures; the value of harmony between theory and practice; and he became cautious of metaphysics, dogmatism, symbols and abstractions. It is no surprise that this common ground would benefit his election.

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[22] R. Sviedrys, "The Rise of Physics Laboratories", *Historical Studies in the Physical Sciences,* **7** (1976), p. 406

[23] See Smith and Wise (1989), quoting W. Thomson from lecture notes (1903), p.38

The teaching of mathematics by William's father had greatly cultivated his mathematical talent. William's family was, however, of further importance. The family's religious convictions were *latitudinarian,* which can be characterized as open-minded and anti-dogmatic. William's brother – also James – would become a successful engineer. Their continuous close contact about their work helps to enforce the notion that William was attracted to challenges of an engineering and practical nature. The family had a humble background, but had risen in wealth. Father Thomson can be characterized as a self-made man, who had worked hard at his education and had managed to acquire wealth through his popular lectures and textbooks. This most probably made William aware of the value of a stable income.

The more elite climate at Cambridge stood in sharp contrast to the University of Glasgow, but they offered what was considered the best mathematical education in Britain. This was the main reason for William Thomson to do his undergraduate studies there from the age of sixteen. His great talent for mathematics indeed became more evident. He wrote multiple very creative mathematical papers under the pseudonym P.Q.R. for the *Cambridge Mathematical Journal* and became Second Wrangler. It was to everybody's surprise that he hadn't become Senior Wrangler, but the student who beat him to it apparently was a faster writer. He got elected, nonetheless, as a fellow at Peterhouse – his college at Cambridge – in 1845. The teachings on Natural Philosophy, though, were still based mostly on the *classical* mathematical tradition and it did not explicitly seek a harmony between theory and practice.

When the candidacy of William Thomson for the chair of Natural Philosophy became a serious possibility, his Cambridge education could actually work against him. The professor of Natural Philosophy indeed had to be affluent in mathematics to adequately deal with this quickly specializing subject. Also the gradual professionalization of this subject required a more rigorous scientific background. Cambridge provided William with both, but the Scots cherished primarily their popular values: "Thus a candidate had above all to be a professional teacher, with the ability to market his expertise to large numbers of fee-paying students." On this point the election committee considered a Cambridge education an impediment. Mostly because they doubted if such a candidate could master and efficiently communicate the experimental part of the Natural Philosophy course. Therefore, William Thomson was strongly advised to strengthen his experimental skills. Besides following the rather provisional experimental courses at Cambridge, some of the members of the election committee advised him particular to go to Paris. There he could further master his experimental techniques, by exposing himself to *la physique experimentale.*

William went to Paris in 1845, where he would cultivate his experimental techniques in the laboratory of Victor Regnault. Regnault's testimonial of William's experimental skills would be an influential tool to disprove the election committee's remaining doubts. Thomson's learning experience at the laboratory of Regnault would fundamentally influence his experimental attitude. Primarily, his continuous appreciation for *precision in measurements* was incited here. The direct consequences of this appreciation will become clear in the following two chapters. Here it suffices to say that Thomson would extend Regnault's precision – coming mainly

from chemistry – to a wider range of subjects in the physical science, for instance, electrodynamics.
Assured of his *mathematical* and *experimental* skills, the election committee unanimously choose William Thomson as the new professor of Natural Philosophy in 1846.

Conclusion

This chapter effectively illustrated that recent reforms had aligned the University of Glasgow with the industrial city. The University now considered its popular aim to be the education of the people, instead of traditional elites. Together with the financial incentive, professors effectively started to *market their knowledge.*

In Natural Philosophy and Engineering the harmony of theory and practice was especially valued: the *usefulness* of science was important. This connotation of usefulness and the actual establishment of an Engineering chair both reinforced the relation with the industrial elite.

In electing a new professor of Natural Philosophy the University, thus, searched for a candidate that was primarily a good *teacher* - they did not explicitly require a professor to engage with industry. The new professor had to be mathematically apt to communicate new French physics effectively, and experimentally skilled to engage the students in the more Baconian part of the course. Alignment with industry had, indirectly, stimulated the integration of Baconian sciences in the course of Natural Philosophy.

Thomson was eventually elected, because he was an excellent mathematician who understood the latest of French discoveries. The election committee had, on the other hand, advised him to enhance his experimental skills in France, which he successfully did.

Thomson's pure scientific side – characterized by his French style mathematics and up-to-date experimental skills – was representative for the University's idea of Natural Philosophy. His (commercially) innovative side had not been able to blossom yet. Glasgow University, however, had not explicitly required such an industrial innovative mind, but an effective teacher. Through its alignment with the industrial city, it offered the perfect place to make Thomson's innovative side blossom. In the next chapter it will be demonstrated how.

Chapter 2

The Establishment of the Glasgow Physical Laboratory

As the new Glasgow professor of Natural Philosophy Thomson maintained the basic outline of the course: it consisted of a *mathematical* and *experimental* part. As a student at Glasgow himself, William Thomson had already been taught the subject in this setup by professor Meikleham. The experimental apparatus that the new professor encountered was of "a very old-fashioned kind"[24]: they mostly offered basic lecture-demonstrations and were usually decades old. William Thomson would set out straight away to modernize this experimental part of the course. With grants from the University Thomson he was able to purchase new apparatus. He even visited Michael Faraday in London to view his instruments related to the investigations into electricity and magnetism. He set up his first modest physical laboratory in an old wine cellar at the University in the late 1840's.

Through his labour at the physical laboratory, Thomson would take further steps in the synthesis of a new experimental methodology. He quickly understood that the laboratory was the prime vehicle of scientific, and industrial progress. In the spirit of Glasgow University he aligned the employment of his laboratory readily with industry. This would be the impetus for his innovative side to blossom: his patents were in essence an extension of his experimental methodology into the realm of industry.

Learning the Art of Experimentation

To strengthen his candidacy for the chair of Natural Philosophy, William Thomson had enhanced his experimental skills at the laboratory of Victor Regnault in Paris for several months in 1845. The apparatus he worked with was at the cutting-edge of *la physique experimentale*. The young Thomson was instantly placed at the forefront of the developments in modern experimental methodology. Regnault mainly investigated the thermal properties of matter – particularly the specific heat of different gasses. Regnault conducted these investigations with the "patronage from a committee of the Ministry of Public Works concerned primarily with the accumulation of accurate data relevant to the safety and efficiency of steam engines."[25] Thus, Regnault's work also exhibited a clear relation between science and industry. Furthermore, the level of accuracy in his measurements was unprecedented.

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[24] See Smith and Wise (1989), p. 87

[25] See Fox and Guagnini (1999), p. 36

Regnault had learned his laboratory techniques himself as a student at the chemical laboratory at the University of Giessen. Justus von Liebig had established it in 1825 and it was the first academic laboratory. An ample amount of new *precise* methods were developed here, leaving their mark.

The young Thomson inherited Regnault's dedication to *precision measurement*, or as he says it himself, "a faultless technique, love of precision in all things, and the highest virtue of the experimenter – patience."[26] This love would resonate in the experimental work at the Glasgow physical laboratory later. The subsequent establishment of the Glasgow physical laboratory was effectively an extension of Regnault's methods into Natural Philosophy.

Pioneering a *physical* laboratory

The primary reason for the establishment of the physical laboratory was the improvement of the *teaching* of Natural Philosophy.[27] This served the direct goal of a university professor to market his knowledge to students. In this he extended the didactic example of the Giessen chemical laboratory, the Glasgow chemical laboratory and the German research seminars. He pioneered however the use of his students as assistants in his own experimental investigations. The initial motive was simply because "the labour of observing proved too heavy."[28]

For the subjects of his investigations he got his inspiration directly from the industrial challenges offered by Glasgow. The chemical laboratories of Regnault, von Liebig and Thomas Thomson all had possessed a strong industrial dimension as well, leaving their marks, respectively, in the engine, agricultural and shipbuilding industry. William Thomson essentially understood very early that the laboratory was an important vehicle for scientific and industrial progress. In the progressive environment of Glasgow University this dedication was readily supported: the establishment of the physical laboratory corresponded to their popular education values and the Scottish believe in harmony of theory and practice.

From the start Thomson would employ methods of precision and absolute measurement, combined with a highly mathematical approach. In the first years of his laboratory Thomson further investigated the thermal properties of gasses. He would develop an absolute temperature scale to properly conduct these researches – the Kelvin scale was named in his honour. His mathematical and theoretical approach allowed him to combine these investigations with Fourier's and Joule's individual findings on heat, culminating in his formulation of thermodynamics. Especially his formulation of the *conservation of energy principle* in his seminal *On the dynamical theory of Heat* (1850) was of great importance: multiple fields within the physical science were now directly linked through the general concept of energy.

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[26] See Smith and Wise (1989), p. 108

[27] G. Gooday, "Precision Measurement and the Genesis of Physics Teaching Laboratories in Victorian Britain", *The British Journal for the History of Science*, **1** (1990), p.25-51

[28] See Smith and Wise (1989), p. 130

His work on thermodynamics also demonstrated an even closer connection with industry, because he explicitly used concepts like 'work', 'waist' and 'efficiency'. These terms have a clear economic connotation, corresponding to the engineering challenges in industry. As mentioned before, the distinction between Natural Philosophy and Engineering was rather fluid. Glasgow engineers like Rankine and James Thomson (William's brother) made contributions to fundamental theory, and scientists like William Thomson fuelled advancement in industry. Again, the Scottish intellectual atmosphere of harmony between theory and practice was the main impetus.

Summarizing, his mathematical approach combined with a dedication precision constituted an important step in the synthesis of a new experimental methodology. The employment of the physical laboratory for his work on thermodynamics was a testament of his conviction that the laboratory was a vehicle for scientific progress. The next great project of telegraphy proved it was also truly a vehicle for industrial progress.

The telegraphic industry was an example of a *science-based-industry*: the recently discovered science of electrodynamics had opened up the possibility of almost instantaneous telecommunication. Between 1854 and 1866 Thomson would be preoccupied mainly with the technical challenge of laying the first Atlantic telegraph cable. Again, he used methods of precision and absolute measurement, and a mathematical approach to offer solutions. The success of the Atlantic telegraph cable in 1866 can be attributed, undoubtedly, for a major part to Thomson's work. In chapter 3 an in depth analysis is given of his work on telegraphy. His first successful patents were registered in relation to this work.

A blossoming innovator

Thomson's work at his laboratory will also help to better understand his innovative side. His innovations were a direct consequence of his dedication to *precision and absolute measurement* in his laboratory. He needed to continuously develop instrumentation that could accurately perform measurements, simply because they didn't exist. This was especially true for experimental apparatus concerned with electrical research. Because Thomson desired the experiments to correspond to the principle of absolute measurement he had to be especially creative: his measuring devices had to correspond to absolute mechanical units, instead of relative human calibration. His effectiveness in developing such instrumentation became evident quickly: he developed sensitive electrometers, like the quadrant electrometer, electrostatic voltmeters and galvanometers. In 1850 he entered a partnership with the Glasgow instrument maker James White to capitalize on their potential.

His work on telegraphy would extend his expertise on sensitive instrumentation into the industrial realm. The challenge of submarine telegraphy had required delicate technical solutions, especially the challenge of receiving weak signals (see chapter 3). Thomson's solution, the mirror-galvanometer, was essentially an industrial application of his laboratory instruments. Almost all of his 70 subsequent patents had the Thomson trademark of being delicate measurement instruments – a sensitive marine compass, an accurate deep-sea sounding machine and precise tide predictors are all prime examples.

The patents made Thomson a wealthy man. He was definitely, but not primarily, motivated by the financial potential. First of all, people sought the harmony between theory and practice in Glasgow, which culminated in direct links between science and industry. These links were reinforced at meetings of the British Association for the Advancement of Science and the Glasgow Philosophical Society. So, Thomson was part of an interrelated society: it was the engineer Rankine that actually advised him to register his first patent for the mirror-galvanometer. Also, professors at Glasgow University had been dependent on the effective marketing of their knowledge, because the student fees provided them directly with a healthy income. It was however not uncommon to further expand such activities by, for example, writing textbooks and consulting local industry. Individual circumstances, though, undoubtedly influenced Thomson financially as well: he came from a family with a humble background and this resonated in his father's constant emphasis on the value of a stable income – this emphasis is clear in letters that he send to William when he was at Cambridge and Paris. The electrical instrumentation would in particular bring him this stable income.

Gradual professionalization

Precise laboratory methods were especially suitable to investigate the general concept of energy that now closely related multiple fields within the physical science: the scale of Thomson's laboratory increased rapidly. In the early 1850's the University already provided him with a larger location for his laboratory. It also meant that the work had to be organized more and more. After a few years Thomson actually employed a fulltime assistant. The main point is that this gradual institutionalisation of the physical laboratory was unintentional. In other words, the University of Glasgow had never required Thomson to establish his physical laboratory; its subsequent success can be mainly attributed to Thomson directly.

The research at the Glasgow laboratory had been crucial to the success of the Atlantic telegraph cable in 1866. The University of Glasgow formally recognized the physical laboratory as a fundamental academic institution as a consequence. When the Glasgow campus moved to a new location in 1870 William Thomson was provided with a new physical laboratory that was "vastly superior in scale and design to the old accommodation."[29] William Thomson had fully extended laboratory methods into the realm of Natural Philosophy. Its value was now widely recognized: in the period 1866-1874 almost ten physical laboratories were established at British Universities and academic institutions. This includes the famous Cavendish laboratory at Cambridge. All of them were modelled in the image of the Glasgow example. At a lecture in 1868 the Edinburgh professor of Natural Philosophy, Peter Guthrie Tait, expressed his enthusiasm for the Thomson's laboratory by noting, "Sir William Thomson's students have for years been doing excellent work, and have furnished their distinguished teacher with the experimental bases of more than one very remarkable investigation."[30] Tait would establish his own physical laboratory at Edinburgh University in the same year. Hence, the physical laboratory became fundamental in the teaching of Natural Philosophy to a new generation of physicists.

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[29] See Smith and Wise (1989), p. 135

[30] See Sviedrys (1976), p. 416; quoting Tait from a lecture in 1868.

Conclusion

In his wish to modernize the experimental part of Natural Philosophy, Thomson acted very much in the spirit of his academic environment; it was a direct improvement in the *teaching* of the course. Also, his interest in industrial subjects was representative for the University's general alignment with the industrial city.

Thomson *pioneered,* though, the establishment of the first *physical* laboratory. He extended laboratory techniques from chemistry to Natural Philosophy – mainly the methods of *absolute* and *precision measurement.* Together with his mathematical approach, Thomson effectively concluded the synthesis of a new experimental methodology. Thomson had understood early on that the physical laboratory was the prime vehicle of scientific progress. His pure scientific side was apparently *ahead* of his environment here.

His (commercially) innovative side truly blossomed due to his laboratory investigations: his patents were in essence an extension of the precise experimental apparatus that he pioneered into the industrial realm. On account of his engagement with industry Thomson was fairly representative for his environment (it was his colleague Rankine that advised him to register his first patent), but on account of the advanced nature of his innovations Thomson's innovative side was *ahead* of his academic environment.

In the next chapter his 'advanced' approach is meticulously investigated.

Chapter 3

The trans-Atlantic Telegraph Cable

The telegraph industry is a good example of a *science-based-industry*, because it was a direct result of the discovery of electrodynamics by Faraday and Ampere. The fact that a current sent from one end of a cable could induce a magnetic field at the other had opened up the possibility of almost instantaneous telecommunication. It didn't take too long before the first real steps in achieving this goal were undertaken. The two main challenges that had to be dealt with were "the mathematical ingenuity in finding the most effective code for transmitting messages by unit signals"; and "the physical problem of sending and receiving these signals."[31] The first challenge was solved effectively through the introduction of an alphabet coding system based on lines and dots by Samuel Morse. The second would require contributions from men like Henry, Gauss, Weber and Wheatstone, who would have to deal with the main technological problems of current generation and propagation. It was no surprise that the most fast-paced innovations in telegraphy occurred in Britain, because the recently developed and rapidly expanding railway network there demanded a mode of almost instantaneous communication. Also the desire of the British Empire to link the different markets of their colonies and other nations overseas offered a powerful industrial incentive for British innovation. This last aim, thus, required the laying of submarine telegraph cables.

The first submarine telegraph cable between Dover and Calais had been laid in the early 1850's, after a very effective insulator had been discovered, so-called *gutta percha*. There seemed to be, however, some unexpected issues: the received signals were weaker and retarded. This would undoubtedly form a major problem when a transatlantic telegraph cable was to be realized that was at least ten times longer. To investigate the problem the telegraph company invited the chief scientist of electrodynamics, Michael Faraday. He concluded that the copper wire and the seawater – separated by the gutta percha – acted as a giant Leyden jar (capacitor) and that the inductive capacitance was the prime reason for the retardation in the signals. This analysis is what directly attracted William Thomson to the problem.

In addressing the problem of the retardation of the signals William Thomson would need his mathematical skills –especially his use of analogy– and his experimental skills – especially his appreciation for precision measurements. But first we will go back a little to look at the birth of electrodynamics, because it illustrates in a most interesting way the main characteristics of the rapidly changing face of physical science that we spoke of earlier and the way in which Thomson's role can subsequently be qualified.

[31] See Bernal (1953), p. 116

A Short History of Electrodynamics

Electric and magnetic phenomena had been observed as far back as Ancient Greece. They knew, for instance, that when you rubbed amber with a piece of cloth, it could give shocks, and that certain metals attracted each other. Also in the late Middle Ages, the tendency of certain materials to point to the North was ascribed to magnetic properties and formed the basis for the compass. The two types of phenomena were perceived though as being very distinct – electric phenomena involved 'violent action' like shocks and magnetic ones showed subtle influence. The question remains if all the phenomena of a specific type were even thought of as interrelated. The first real step to lifting these merely interesting phenomena to proper research fields came with the rise of Baconian sciences in the sixteenth century.

The new empirical method of Baconian science that favoured an unprejudiced experimental attitude in which Nature was constrained, would officially give rise to the fields of electricity and magnetism. In their investigations the practitioners developed increasingly innovative ways of demonstrating, in particular, electric phenomena. The head of demonstrations at the Royal Institution of London in the beginning of the eighteenth century, Francis Hauksbee, developed the so-called 'Hauksbee machine', which was in essence the first electricity generator. It was this machine that Stephen Gray used to electrostatically charge himself, by suspending himself with silk wires above the ground, enabling him to attract gold leafs with his hands. This small experiment wasn't just a funny demonstration, but led Gray's inquisitive mind to classify materials into conductors and insulators. The Hauksbee machine was also used by Van Musschenbroeck to investigate the possibility of storing electricity that would culminate in the discovery of the Leyden jar – the first primitive capacitor. All these discoveries rapidly exposed the wide interconnected field of electricity. When Benjamin Franklin conclusively demonstrated the electric nature of lightning, people really understood the full reach of electricity as a fundamental force of Nature. More importantly, they now saw that this force of Nature could be understood with rationality – in the spirit of the Enlightenment – and possibly be controlled. This would directly lead to the first mathematical theories of electricity. And further experimentation would demonstrate the electromagnetic connection.

As mentioned before, the French had taken the lead in the mathematization of scientific fields in the final decades of the eighteenth century into the early nineteenth century. The first quantitative mathematical theory on electrostatics came in the 1780's, thus unsurprisingly, from a French military engineer, Charles Coulomb. His fundamental law is still the basis of electrostatics today. The discovery of the effects of *moving* electricity was however still quite chaotic, merely empirical and un-mathematical. Volta had shown that with his 'Voltaic pile' a constant effect of moving electricity was observed – an electric current. This was in essence the first electrochemical battery. The more advanced Daniel Cell, for instance, was derived from his original setup. The true underlying mechanism remained, however, a subject for speculation, but it would allow Hans Christian Oersted to establish the electromagnetic connection. This Danish scientist discovered through a series of experiments that a current-carrying wire was able to deflect a compass needle, thus, he concluded that a current induces a magnetic field. Electricity and magnetism were now truly connected.

It would again take a French scientist to offer the first mathematical theory of this connection, Marie-Andre Ampere. His theory described the forces between two currents and how magnets and distributions of current were equivalent. Michael Faraday would demonstrate how a magnetic field could induce a current, as a reciprocal to Oersted's induction. They are the true inventors of electrodynamics. Both of them relied on experimental facts for their conclusions, but they differed strongly on their scientific attitude. Ampere was highly theoretical and his experimentation generally aimed at verifying his predictions or to decide between a preconceived range of theoretical possibilities. Faraday, though, was non-mathematical and approached his experiments unprejudiced. His aim was to 'place the facts close together' to deduce their relation.[32] In this sense we can classify Ampere's experimental attitude as overall *classical*, and Faraday's as more *Baconian*.

In Germany the notion of *precision* would truly enter the field of electrodynamics. Men like Ohm, Gauss, Weber, Neumann and Kirchhoff extended the quantification of electrodynamics by aiming for complete mathematical theories in correspondence with the precision measurement of observable quantities and relative constants. Weber was dedicated to the principle of *absolute measurement* – the reduction of the relevant units to absolute mechanical and geometric units. In essence this expels the relative calibration of measuring equipment and introduces universally adoptable units. The highly innovative character of Weber's experimental apparatus – and experiments in general – is broadly attributed to his dedication to this *absolute measurement* principle. This is particularly interesting, because Thomson seems to have been heavily influenced by and dedicated to Weber's principle himself.

The maturing field of electrodynamics had quickly exhibited the industrial potential of almost instantaneous telecommunication, as mentioned above, but it had come a long and most interesting way from its humble beginnings in Antiquity. Thomson would play an important role in the further advancement of the field, starting with his involvement with the submarine telegraphy problem.

Thomson's scientific approach to a practical problem

Thomson became attracted to the problem of submarine telegraphy by Faraday's analysis of signal retardation in these transmission cables in 1854. Faraday had attributed the main cause of the problem to the immense inductive capacitance of the cable: the conductive seawater allows the build up of charge on the outside of the gutta percha, due to induction whence the copper wire becomes charged. He believed that longitudinal induction – which according to Faraday always preceded conduction – now had to compete with the lateral induction through the gutta percha. Thomson would effectively analyse the problem himself and subsequently point out the direction of possible solutions. He would need his mathematical skills for this, in particular his ability to highlight analogies between different theories.

[32] O. Darrigol, *Electrodynamics from Ampere to Einstein* (Oxford, 2000), chapter 1

Thomson would use several heat analogies to analyse this electrical problem. His heat analogy was deeply rooted in Fourier's Analytical Theory of Heat, which had continuously inspired Thomson from a young age. Fourier's methodology contrasted somewhat with the purely analytical mathematics of, for instance, Laplace, because geometric concepts were also present – the notion of flux across a surface for example. This geometric representation corresponded to the general British reluctance towards abstraction and Fourier's methodology understandably caught on there – James Green adopted it heavily in his work. Thomson was also dedicated to another, more Scottish ideal, that of non-hypothetical theory. Concretely this means that an analogy only holds if transposed terms are know to physically exist.

He first used a heat analogy for electrostatic induction to calculate the inductive capacity of the telegraph cable. He argued that the electric force in the gutta percha radially outward was analogous to the heat flux through the gutta percha when the copper wire and the water were held at a constant temperature difference. Along a certain length of the wire, the flux must however be conserved. This flux conservation gives us what we recognise now as Gauss's law. He found the capacitance of the wire to be:

$$c = \frac{K}{2 \log \frac{R'}{R}}$$

where "[K] denote the specific inductive capacity of the gutta percha, and R, R' the radii of its inner and outer cylindrical surfaces."[33] This corresponds to the well-known expression for the inductive capacity of a cylindrical capacitor.

Next he would use a heat analogy for the longitudinal conduction process. While studying Faraday's explanation he instantly observed the problem of submarine telegraphy as analogous to the longitudinal heat conduction through a rod whose ends where held at different temperatures. The lateral induction process was in this case analogous to the heat capacity of the material, or in other words, he regarded it "as a constant capacity for holding electricity on the central conducting wire."[34] He explained this approximation by noting that the inductive action occurred almost instantaneously round each point of the wire, thus "the potential at the outside of the gutta percha may be taken as at each instant rigorously zero."[35] The main cause of the retardation was thus the capacitance of the wire, not the induction.

With this setup Thomson was now able to get "the equation of electrical excitation in a submarine telegraph-wire, perfectly insulated by its gutta percha covering."[36]

[33] W. Thomson, "On the Theory of the Electric Telegraph", *Proc. Roy. Soc. Ldn.*, **7** (1854-1855), p. 383

[34] See Smith and Wise (1989), p. 449

[35] See Thomson (1854-1855), p. 383

[36] Ibid.

The quantity of electricity (Q) on a length dx at a specific point (P) on the wire at a time t, was:

$$Q = v\ c\ dx$$

where v is the potential at the point and c is the capacitance of the wire. The change in time of Q is:

$$\frac{dQ}{dt} = c\ dx\ \frac{\partial v}{\partial t}$$

Now, if R is the resistance of the wire "in absolute electro-statical measure" and I the current at point P at time t, we also now:

$$\frac{dQ}{dt} = -\frac{dI}{dx}dx$$

Furthermore, from Ohm's law Thomson also knew:

$$R\ I = -\frac{dv}{dx}$$

Combining gives the obtain the required equation:

$$c\ R\ \frac{dv}{dt} = \frac{d^2v}{dx^2}$$

Unsurprisingly, Thomson concluded: "this equation agrees with the well-known equation of the linear motion of heat in a solid conductor; and various forms of solution which Fourier has given are perfectly adapted for answering practical questions regarding the use of the telegraph-wire." For a quick rise of the potential at the sending end of the cable – the actual signal – he could solve the differential equation using Fourier's methods. From his solution Thomson could "infer that the time required to reach a stated fraction of the maximum strength of current at the remote end will be proportional to $R\ c\ l^2$."[37] This 'law of squares', thus, gave the transmission time of signal in a submarine cable with length l.

With this theoretical – *very scientific* – approach Thomsons was now able to predict the performance of submarine telegraph cables. The two main solutions to decreasing the retardation of signals were thus: the decrease of the wire's resistance (*R)* by increasing the copper wire parameter; and the decrease of the capacitance (*c*) by an increase of the diameter of the insulating gutta percha. Now, the problem was reduced to "an economical problem, easily solved by the ordinary analytical method of maxima and minima, to determine the dimensions of wire and covering."[38]

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[37] See Thomson (1854-1855), p. 388

[38] Ibid. p. 389

An engineer at work
The next step for William Thomson was to put his theoretical analysis into useful practice. He had become a director on the board of the Atlantic Telegraph Company in 1856 and was, in turn, even more dedicated to the success of the project. In his physical laboratory in Glasgow (see chapter 2) he started to accurately measure the resistance of copper from various manufacturers. He was motivated to do so, because his law of squares had demonstrated its crucial role in the performance of the cable. He investigated four kinds of copper of different manufacturers and found that "greater differences in conducting power were discovered than any previously observed."[39] Thus, he emphasized, "how important it is to shareholders in submarine telegraphy companies that only the best copper wire should be admitted for their use."[40] This conclusion seems trivial to us today, but was very relative back then. This will become especially clear in the context of the failure of the first Atlantic Telegraph cable in 1858, which I will elaborate on later.

Two more interesting facts can be pointed out regarding his investigation into the conductivity of copper. First, as he put it himself, "the cause of these differences in electrical quality is a question not only of much practical importance, *but of high scientific interest.*"[41] He found out that the main difference was dominantly due to the chemical composition – level of impurity – of the copper, not the mechanical quality – brittleness, spiralling form etc. Second, he was dedicated to Weber's principle of absolute measurement, because he used a suitable unit that "has been determined for me in absolute measure through the kindness of Professor W. Weber."[42]

In his paper *On practical methods for rapid signalling by the electric telegraph* (1856) Thomson explicitly explains his thoughts on a suitable telegraphic system. He proposed to use a "regulated galvanic battery" that would produce the electric signals with a delicate current. To receive messages on the other end he proposed a sensitive "Helmholtz's galvanometer, with or without modification."[43] (Thomson's *mirror galvanometer* was such a modification and would be one of his most successful patents. We will come back to this example later.) Another statement in his paper about the value of his telegraphic system is particularly interesting for our narrative: "whether or not this system may ultimately be found preferable to the very simple and undoubtedly practicable method of telegraphing invented by Mr. Wildman Whitehouse, can scarcely be decided until one or both methods shall have been tested."[44]

Wildman Whitehouse was the chief electrician of the Atlantic Telegraph Company during the realization of the first Atlantic telegraph in 1858. He was, however, highly critical of Thomson's proposed solution.

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[39] W. Thomson, "On the Electric Conductivity of Commercial Copper of Various Kinds", *Proc. Roy. Soc. Ldn.*, **8** (1856-1857), p. 551

[40] Ibid. p. 552

[41] Ibid.

[42] Ibid. p. 554

[43] W. Thomson, "On Practical Methods for Rapid Signalling by the Electric Telegraph", *Proc. Roy. Soc. Ldn.*, **8** (1856-1857), p. 301

[44] Ibid. p. 304

Wildman Whitehouse was an engineer, who had an un-mathematical and un-theoretical approach. He favoured practical observations and clear facts; in a way he was the typical "rule-of-thumb" engineer. This was the predominant attitude of engineers at that time in Britain. With regard to the Atlantic telegraph Whitehouse essentially believed that it was just a case of 'scaling up' the Channel telegraphic system. Thomson's considerations were mostly ignored for the first cable.

The first Atlantic telegraph cable was laid in 1858 between Ireland and Newfoundland. Thomson was on board during the laying process. After the connection was successfully made, the performance of the cable almost instantly declined: it took hours to sensibly receive messages. Whitehouse, in an attempt to force the electricity through increased the current. In his mind this was like increasing the pressure on a fluid in a pipe. The cable almost immediately broke down. An inquiry into the failure of the cable concluded that Thomson's precise methods and instrumentation could be the only basis for success.

The project would take another eight years, but now Thomson's considerations were readily implemented. Precision methods were now used at the cable manufacturer to make sure the quality of the copper and gutta percha was sufficient. The dimensions of the cable were also adequately increased. To efficiently communicate the relevant electric quantities in science and industry, Thomson advised the British Association for the Advancement of Science in 1861 to create a committee that would decide on the standard of electrical resistance. As a chairman of this committee he would use an absolute system of electric units (in the spirit of Weber) based on the mechanical units of work, time and length. This system would form the basis for the international units we still use: Ohm, Farad, Coulomb and Ampere.

The requirement of absolute and precise measurement in electrical research, and sensitive apparatus in the telegraph industry called for the development of new instrumentation. Thomson was highly successful in developing such sensitive instruments. The environment of his physical laboratory offered the workplace needed. In his forty-year-involvement with the telegraph he would register 12 patents. His most successful were the mirror-galvanometer and the siphon recorder. Both were receiving devices that could detect the weak signals in long-distance submarine telegraphy. In the mirror-galvanometer the received signal induced a magnetic field that moved a mirror. A light beam on the mirror was deflected, which could be observed and interpreted. The siphon recorder was an expensive device that had the sensitivity of the mirror-galvanometer, but actually *printed* the message automatically. Most telegraph companies used these instruments – and subsequent improvements – for decades. They would make William Thomson his first wealth.[45]

The maturing process of electrical research in the 1850's and 1860's was carried by the telegraphy industry. It had ensured the development of *relatively cheap* and *widely available* electrical research apparatus,

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[45] M. Trainer, "The Patents of William Thomson (Lord Kelvin)", *World Patent Information 26* (2004), p. 311-317

like electrometers, insulated wires and current generators. This paved the way for further electrical research: the industries of electric light and power were a direct result of further research, as was Maxwell's seminal *Electromagnetic Theory of Light.*

His theoretical and experimental work; his development of new electrical instrumentation and his contributions to the professionalization of the electrical industry and science were all of great importance to the final success of the Atlantic telegraph cable in 1866. Communication had changed from a matter of weeks to a matter of seconds. His crucial role was publicly recognised by his knighthood. He was now *Sir* William Thomson.

Conclusion

Sir William Thomson's work on the Atlantic telegraph cable effectively illustrates multiple things. First it gives an example of his interest in engineering and, more deeply, of his Scottish conviction to the useful application of science. Furthermore, it illustrates the mathematical nature of his theoretical approach towards such interests: he puts his French inspired mathematics to full use, especially Fourier's methodology.

His work also demonstrates how his experimental attitude of precision and absolute measurement in his Glasgow laboratory benefited both theory and practice. His experimental attitude, in turn, shaped the character of his innovations: the most successful patents were delicate apparatus that ran on the principle of absolute units.

The contributions he made to the success of the Atlantic telegraph cable would firmly establish the value of a scientific approach in engineering, in contrast with the "rule-of-thumb" attitude. It was a major step in the academic professionalization of engineering. As pointed out in chapter 2, the advancement of electrical research was carried by the work on the electric telegraph. This provided the "stock-in-trade" for further professionalization of scientific electrical research. It would, thus pave the way for the industries of electric light and electric power, and the theory of Maxwell.

With his work on the Atlantic telegraph Sir William Thomson operated at the intersection of science and industry. This cross-cultural position was beneficial for the advancement of both.

Conclusion

This part returns to conclusively answer the main question: *in what way was Sir William Thomson's two-sided character –namely his pure scientific and (commercially) innovative side– representative for his academic environment?*

At the time of his election as Glasgow professor of Natural Philosophy, Sir William Thomson's pure scientific side *represented* the University's requirements. He had even been advised by several members of the election committee to strengthen his experimental skills.
Due to recent reforms the University of Glasgow considered its aim to be the *education of the people*. Hence, when they were looking for a suitable candidate for the vacant chair of Natural Philosophy, they required, above all, good teaching skills. This was translated in a wish for *mathematical aptitude* – to effectively communicate new theory – and experimental skills – to teach the experimental part of the course. The election committee did not explicitly look for an innovator.

On a more general note, the recent reforms had gradually aligned Glasgow University with the industrial city. In Natural Philosophy and Engineering, for instance, the harmony of theory and practice was especially valued: the *usefulness* of science was important. This industrial setting allowed for Thomson's innovative side to thrive.

First he had to *pioneer* a new scientific approach. Thomson established the first physical laboratory and cultivated a new experimental methodology, based on *precision measurement* and *mathematical theory*. He quickly understood that his laboratory was the prime vehicle for the progress in science. His pure scientific side had come *ahead* of his academic environment on this.

He also understood that his laboratory was the prime vehicle for industrial progress. Challenges in the telegraphy industry had required his scientific approach. His innovations for the telegraphy industry were, in essence, extensions from his sensitive measuring apparatus in his laboratory into industry. Though his engineering colleague Rankine had advised him to register his first patent, this does not mean that the University generally expected such innovation from its professors. The scientific and advanced nature of his innovations again put him ahead of his academic environment.

Summarizing, the combination of Thomson's mathematical talent, excellent experimental methods guided by precision and inclination to engineering problems made him unique. The University of Glasgow offered the perfect place to cultivate its offspring, because it aligned with industry itself.

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