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Jaume Navarro
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Introduction

In 1897, Joseph John Thomson, Professor of Experimental Physics and director of the Cavendish Laboratory in Cambridge, ascribed corpuscular nature to the carriers of electricity in cathode rays. This event constitutes a central element in what is traditionally known as the *discovery* of the electron. Exactly 30 years later, his son, George Paget Thomson, obtained the first ever images of electron diffraction, with which he showed the wave-like behaviour of his father's electrons. Ironically, while the father had shown that a wave phenomenon (cathode rays) could be explained in terms of corpuscular entities (electrons), the son was reclaiming wave characteristics for his father's corpuscles. This is, in a nutshell, the story of this book, one that, however familiar to many physicists and historians of science, has never been told in detail.

Alongside this father-and-son narrative, I intend to explore a number of historiographical and philosophical questions. To begin with, this book is biographical, but not a traditional biography. The main characters on the stage are J. J. Thomson, G. P. Thomson and the corpuscle-electron, and the book deals with the intersection of their lives. There are a number of partial biographies of J. J. Thomson, starting with his own memoirs (Thomson, 1936; Rayleigh, 1942; G. P. Thomson, 1964; Davis and Falconer, 1997; Kim, 2002), but nobody has so far written a complete biography of him. Just from counting the pages in this volume, it is clear that this book is no attempt to plug this bibliographical lacuna. But it does enter into an aspect of his career often overlooked: his science in the 1920s, when a young generation of physicists regarded him as a relic of times past. As I shall argue in Chapters 5 and 6, an examination of his work in those years sheds some new light on the content and motivation of the better-known aspects of his career. Nor does a biography of G. P. Thomson exist. Indeed, there has been surprisingly little historical work done on him for a man who was inter alia a Nobel laureate in physics, chairman of the MAUD committee, and Master of Corpus Christi College, Cambridge.

As for the electron, a number of *biographies* of this entity do exist, from Charles Gibson's (1911) *Autobiography of an Electron* to Theodore Arabatzis' (2006) *Representing Electrons*, the latter being a very good case study for a biography of an epistemic object (Daston, 2000). The present book treats the life of the electron only insofar as it impinges on the Thomson household, from its conception as a corpuscle for explaining cathode rays and the conduction of electricity in gases to its maturity as the first quantum particle with wave properties. We shall see that, as an epistemic object, this electron underwent a number of upheavals and personality changes (continuing with the metaphor) in order to play an explanatory role in an increasing number of phenomena: from cathode rays and atomic constitution to electronic radiation, chemical bonding and quantum indeterminacy. We shall see how this flexibility was possible partly on account of its ontological under-determination. In other words, J. J Thomson's electron did not exist as an ultimate explanation of what matter *is*, but rather as an epistemic object mediating between observed phenomena and the ultimate reality of a continuous ether and the Faraday tubes therein.

As a matter of fact, one could read this book as a biography of Faraday tubes rather than the electron. To be sure, the ether itself is the underlying entity in this story, since it was the ether that embodied J. J. Thomson's belief in a metaphysics of the continuum. Faraday tubes began as a concrete mental model within this continuous framework and slowly almost acquired physical reality in his theoretical work. As we shall see, Thomson expected them to be the underlying entity that might explain the nature of electrons and the seemingly contradictory properties of different forms of radiation. Soon after J. J. Thomson had found evidence for the atomicity of electric charge, physics began to move towards a more fundamental atomicity, that of energy. With the new quantum theory, the fundamental tenets of Thomson's world-view began to tremble, the existence of the ether was in jeopardy, and the laws of classical physics proved to be insufficient for explaining certain phenomena. The problem of accounting for the apparently self-contradictory behaviour of radiation, at times like corpuscles, at other times like waves, loomed large in Thomson's work, which famously led him to coin the expression that physicists were witnessing *a struggle between a tiger and a shark*. Faraday tubes were, for him, the tool that might educe harmony between continuity and discontinuity in the physical world.

Furthermore, G. P. Thomson's experimental demonstration of the wave-like behaviour of electrons confirmed J. J.'s lifelong-held metaphysical views that gave priority to a continuous medium (the ether) rather than to the corpuscular explanations of matter (the electron), the latter being, in his own words, *a policy, not a creed*, on the nature of matter. That is why both father and son could easily accept electron diffraction, since it did not seriously challenge, but rather somehow confirm, their classical world-view. In a way, the Thomsons saw in one of the tenets of the new quantum (i.e., discrete) mechanics, wave–particle duality, confirmation of the classical notion of continuity.

J. J. Thomson's discovery of the electron has always been historiographically problematic. As Isobel Falconer (1985, 1987, 1989) thoroughly showed, his research, from his appointment as Professor of Experimental Physics in 1884, had little to do with cathode rays. He was mainly interested in electric discharges in tubes as a way of understanding the relationship between matter, electricity, and chemical bonding. His interest in cathode rays only came about after the discovery of X-rays in 1895. His electron – the corpuscle – was gradually introduced into explanations of the conduction of electricity, the composition of matter, and chemical bonding. The different uses of the electron were crucial in determining its ontological status: first, in his attempts to obtain a complete explanation for the conduction of electricity and the interaction between electricity and matter, later (and only later) in its role as a subatomic particle. The notion of the corpuscle also permeated his project on positive rays, which he started around 1907, and in which he tried to emulate his experiments on cathode rays in the search for some possible *corpuscle* of positive electricity. He also made frequent incursions into the territories of chemistry, his 1923 book *The Electron in Chemistry* being the highlight of these attempts. The broader picture of the uses of the electron in the first decades of the twentieth century can be found in Buchwald & Warwick (2001).

This biographical sketch of the Thomsons, father and son, of the electron, and of the ether and its Faraday tubes is set on a very particular stage: the University of Cambridge and the Cavendish Laboratory. The book follows in the footsteps of Andrew Warwick's (2003a) *Masters of Theory*, wherein he uses the pedagogical traditions of the Mathematical Tripos as the explanatory tool to evaluate the strengths and weaknesses of the theoretical physics that was done in that university at the end of the nineteenth century and beginning of the twentieth. In that book, Warwick justified the particular way Cambridge (and, by extension, British) physicists understood the new theory of relativity as the almost inevitable outcome of local pedagogical régimes. Here, we shall find a somewhat analogous story in the case of the early theory of the quantum. J. J. Thomson's reaction to the emergence of the new theory, one that challenged the very essence of what science was for him, may be easily interpreted as paradigmatic of a generation of scientist for whom physical explanations had to involve some kind of mental model. Less obvious is G. P. Thomson's case. Trained in Cambridge in the years immediately before the Great War, he was a contemporary of Niels Bohr and could have, in principle, played an active role in the reception and development of quantum physics in Britain, more so when we consider how his experiments on electron diffraction constituted proof of one of the most counterintuitive principles of the new physics. But, as we shall see, he did not construe his work as an *experimentum crucis* standing between the old and the new physics, but merely the confirmation that an explanation in corpuscular/discrete terms only was not enough to resolve the problems of radiation and account for the identity of subatomic particles.

Cambridge will also figure in an unexpected way. After his graduation, G. P. Thomson joined his father in pursuing a research project on the nature of positive rays, one that began as an attempt to understand the nature of positive electrification, later to evolve into a technique of chemical analysis. After the Great War, during which father and son each worked on different military-related projects, they went back to working together again. I shall refrain from making psychological speculations on the kind of emotional dependency the son had on the father, for which we do not have specific evidence. What is of interest is that this reunion happened at a time when J. J. Thomson had been encouraged to step down as director of the Cavendish Laboratory after 35 years' tenure, and that the collaboration did not cease even when, in 1922, G. P. Thomson was appointed as a professor at the University of Aberdeen. As I shall argue in Chapter 6, the son used this first opportunity he had of running a research laboratory, however small it was, to replicate in Aberdeen the experimental set-up he had with his father in Cambridge, virtually turning his laboratory into an extension of his father's old rooms at the Cavendish.

There is one last parallel between the father's and the son's experimental work on electrons that I highlight in this book. As we shall see in Chapter 3, J. J. Thomson had been working on electrical discharges in tubes filled with gases for over ten years when X-rays appeared on the stage. The latter were obtained in cathode-ray tubes, i.e., evacuated tubes, and Thomson's experimental setting could rather easily be modified to analyse the new X-rays and the old cathode rays. His famous experiments of 1897 were, in a way, the serendipitous outcome of a long project that had positively avoided the use of cathode rays. Similarly, in 1923, Louis de Broglie suggested that electrons, and indeed any other particle, could be understood as possessing a dual nature: wave and particle. In the summer of 1926, many British physicists learnt of de Broglie's theory and Schrödinger's developments in quantum mechanics, and it so happened that G. P. Thomson was in a privileged situation to put this principle to the test. His experimental set-up in Aberdeen for studying positive rays could, again, rather easily be adapted to take pictures of the possible diffraction of cathode rays through thin metallic films. Both the discovery of the electron by the father and that of its diffraction by the son were possible thanks to the quick modification of experimental set-ups originally meant for other projects.

Whether matter and radiation are by nature continuous or discrete are central considerations in this book. But I shall also discuss the continuity, or lack thereof, between scientific disciplines, specifically between physics and chemistry, and the nascent field of physical chemistry. The emergence of the last is largely related to the explanatory power of electrons for chemical bonds. In Chapter 2, we shall find, however, that, from the early 1880s, J. J. Thomson had in mind the idea of uniting physics and chemistry under the common umbrella of *the physical sciences*, on both the conceptual and the institutional levels. That particular project did not succeed, but it revises the customary image of J. J. Thomson, who can be understood better as a practitioner of the physical sciences than simply as a physicist. This will also become evident in Chapter 5, when we find the Thomsons' project on positive rays developing into an experimental method of chemical analysis.

Now it is time for acknowledgements and expressions of gratitude. Lest the reader be bored, I shall only mention those who had a very active role in the genesis of this book, starting with Andrew Warwick, who has lent much-needed support at various stages of this project. I should also like to mention Simon Schaffer and Richard Noakes, in Cambridge, and Massimiliano Badino and Shaul Katzir, of the Max Planck Institute for the History of Science, for their insightful ideas and their very helpful advice, as well as the ideas I received from conversations with Hasok Chang and Isobel Falconer, among others. I also want to thank Sebastian Hew for his patient and thoughtful editing of my writing. I am indebted to staff at the following archives for their help and for granting permission to work and cite from their materials: Cambridge University Library (CUL), Royal Society (RSA), Royal Institution of Great Britain (RI), University of Aberdeen (UAb), Trinity College and Churchill College. Lastly, I want to thank Mr David Thomson, son of G. P. Thomson and grandson of J. J. Thomson, for his time and help, and for permission to quote from his father's archives and autobiography in Trinity College, Cambridge.

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1

The early years in Manchester and Cambridge

1.1 Manchester

Chimneys are the main architectural element that characterize our first destination, Manchester in the mid-nineteenth century. Chimneys have dwarfed the bell towers of the old provincial town, and the clangour of the looms has silenced the bells. The power of the steam engine, of the free market, and of enterprise has transformed the city into the centre of what we now call the Industrial Revolution: a landscape of chimneys, like those later portrayed in the paintings of L. S. Lowry, ceaselessly belching smoke into the always-humid air of the Lancashire region. As a contemporary observer put it, 'the clouds of smoke vomited forth from the numberless chimneys, Labour presents a mysterious activity, somewhat akin to the subterraneous action of a volcano' (Fraucher, 1844, p. 2).

Smoke from the factories mingled with steam, with clouds, and with fog, forming all sorts of capricious combinations of fluids and giving rise to playful shapes in the atmosphere. In the mid-nineteenth century, the citizen of Manchester was constantly breathing the insalubrious air created by the industrial machinery: an air that imbued everything in the city, impregnating clothes, buildings and the deep corners of every lung, with terrible odours, dirt and all sorts of diseases. Not only did the Manchester air, like that other entity of Victorian science, ether, permeate many aspects of life, irrespective of social class or age, it was also the source of awe for those interested in the study of fluids, their mixtures, their shapes and forms, and their diffusion through solid bodies. The skies in Manchester became a privileged environment wherein to observe the behaviour of smoke rings, diffusion patterns, and condensation phenomena, all of which were part of the interest of the Victorian men of science.

The better-off classes were also fortunate to experience the different concentrations of that air, since they tended to live in the suburbs of the city, where the atmosphere was significantly cleaner. In a most poignant description made in 1844, Friedrich Engels pointed out the fact that 'Outside, beyond this girdle, lives the upper and middle bourgeoisie, the middle bourgeoisie in regularly laid out streets in the vicinity of the working quarters … the upper bourgeoisie in remoter villas with gardens in Chorlton and Ardwick, or on the breezy heights of Cheetham Hill, Broughton, and Pendleton, in free, wholesome country air, in fine, comfortable homes' (Engels, 1845/1887).

The ubiquitous chimneys were only the tip of the iceberg of the changes that Manchester underwent in the early nineteenth century. In less than a hundred years, the city became the region with the highest density of population in England, seeing a ten-fold increase in the number of inhabitants. The following figures speak for themselves: the population grew from about 24 000 in 1773 to over 300 000 in 1841. The figures, however, belie the most significant change in the structure of the population. At the end of the eighteenth century, in the Mancunian population there was a provincial elite of clergymen, physicians and small-scale traders. By the mid-nineteenth century a growing bourgeoisie of textile industrialists had replaced this elite.

Besides the old and new elites, thousands of working-class people were crammed into neighbourhoods built specifically for them where they lived in subhuman conditions. The descriptions of Friedrich Engels, however exaggerated they may be, give us a vivid account of the landscape: 'Of the irregular cramming together of dwellings in ways which defy all rational plan, of the tangle in which they are crowded literally one upon the other, it is impossible to convey an idea … the confusion has only recently reached its height when every scrap of space left by the old way of building has been filled up and patched over until not a foot of land is left to be further occupied'. And with this chaotic and very dense concentration of human beings came the highest degree of filth and insalubrious conditions: 'In dry weather, a long string of the most disgusting, blackish-green, slime pools are left standing on this bank, from the depths of which bubbles of miasmatic gas constantly arise and give forth a stench unendurable even on the bridge forty or fifty feet above the surface of the stream' (Engels 1845/1887). The social structure of Manchester and its division of labour was also embodied in the strict separation between the different neighbourhoods:

> The town itself is peculiarly built, so that a person may live in it for years, and go in and out daily without coming into contact with a working-people's quarter or even with workers, that is, so long as

> he confines himself to his business or to pleasure walks. This arises chiefly from the fact, that by unconscious tacit agreement, as well as with outspoken conscious determination, the working-people's quarters are sharply separated from the sections of the city reserved for the middle-class; or, if this does not succeed, they are concealed with the cloak of charity … And the finest part of the arrangement is this, that the members of this money aristocracy can take the shortest road through the middle of all the labouring districts to their places of business without ever seeing that they are in the midst of the grimy misery that lurks to the right and the left.

This social structure has also strong parallelisms with the main entity of Victorian physics: the ether. If the mixture of smoke, fog, and air created a privileged image for the structure of the ether, the social structure of Manchester resembled the relationship between ether and the material world. The working class, together with the coal, would have been the invisible power behind the rise in production. The consumer, the middle and upper classes, would only see the result of the process, without getting into the minutiae of the conditions of the working class, their activities, and their work. Analogously, the invisible ether would permeate the activities of the visible world, being the see for diverse forms of energy and, in some cases, also the see for the spiritual world. The ether permeated the whole of the cosmos in Victorian science, and will be present throughout this book. That is the reason for starting with these two analogies that can be found in mid-nineteenth-century Manchester, the hometown of Joseph John Thomson.

1.2 Science in Manchester

The profound changes in the social structure of Manchester triggered in its citizens a transformation in their approach to science. At the end of the eighteenth century, science was almost non-existent in Manchester. Located between the scholarly centres of the south (Oxford, Cambridge and London) and the north (Scotland), Manchester was something of an academic desert. The Mancunian gentry were content with the less-than-exciting intellectual life of local institutions, such as the parish halls, the libraries, the clubs, and the amateur theatres. In just over 50 years, however, the panorama had changed completely. Triggered by the new economic situation, science developed in Manchester in the first decades of the nineteenth century basically because of two factors. On the one hand, the development of industrial machinery and technologies stimulated an army of engineers, chemists and other technical

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personnel, creating the need for spaces to exchange information. On the other hand, some of the entrepreneurial traders and industrialists that populated the city felt the need to relate to nature in a purer way than industry allowed. This gave rise to a particular brand of *savants of nature* composed of successful industrialists for whom the social status came from their philosophical interest in nature, not from the money they made using its resources.

At the turn of the nineteenth century, the only institution in which natural philosophy was somewhat present was the Manchester Literary and Philosophical Society (the Lit & Phil), which originated in the last third of the eighteenth century as informal meetings of mainly medical doctors and was formally established in 1781 (Cardwell, 2003). Initially, the number of ordinary members could not exceed 50, and these were elected on the grounds of their residency in Manchester and surrounding areas, and most importantly, on the basis of their literary or philosophical contributions. The meetings of the society, and the subsequent *Memoirs*, dealt with topics such as natural philosophy, chemistry, literature, civil law, commerce and the arts. Excluded from these debates were British politics, religion, and the practice of medicine in an attempt to avoid belligerent disputes among the members of the Society. In due course, other scientific institutions appeared in Manchester: in 1821, the Natural History Society was established, and soon after the Royal Manchester Institution; in 1825, the Manchester Mechanics' Institution; in 1829, the New Mechanics' Institution; in 1839, the Salford Mechanics' Institution; in 1834, the Statistics Society, and in 1838 the Manchester Geological Society. However, the Lit & Phil maintained pre-eminence over the rest.

Most members of the Lit & Phil were amateur intellectuals. They had their jobs as doctors, chemists, industrialists or tradesmen, but devoted part of their time to the gentle cultivation of the sciences or the arts. Among this very amateur and dilettante tradition, and in contrast with it, we find the best-known Mancunian natural philosopher, John Dalton, a self-trained natural philosopher, who became a member of the Society in 1794 and presided over it from 1817 until his death in 1844.

Dalton's background and attitude towards science meant a first turning point in the nature of the Lit & Phil. He was not a well-established professional, nor did he come from a bourgeois background. He was born into a family of religious dissenters, for whom many educational institutions were, at the time, banned. He started his career in the context of Quaker educational institutions, and arrived in Manchester as a teacher of natural philosophy in a newly created college. His work on meteorology soon gave him local prestige, a prestige he used to become a full-time man of science. The members of the Lit & Phil agreed to let Dalton work in rooms of the Society, which he equipped at his own expense, and from which he emerged as an internationally renowned natural philosopher. It was in the setting of the Lit & Phil that Dalton developed his atomic theory of matter, giving precise, quantitative data on the proportion of the different elements in chemical compounds. Dalton's name would, for evermore, be linked to the atomic theory of matter.

The importance of Dalton as an icon of Manchester science was particularly clear during his funeral, on 12 August 1844, an event that was tailored by the local authorities to signal Manchester as a place for first-rate natural philosophy. According to the reporter in *The Manchester Guardian*, the chapel of rest, installed in the Town Hall, was visited in one day 'by no less than forty thousand people'. In the procession to the cemetery, 'nothing could be more gratifying than the quiet, orderly behaviour, and the silent and respectful demeanour, of the immense concourse of persons along the whole distance … The shops were closed; ladies and gentlemen, in mourning, filled every window … Indeed, we never saw in this community so general a wearing of mourning attire, crape, &c.' (*The Manchester Guardian*, Wednesday 14 August, 1844). Such ostentatious display was condemned only by the Society of Friends, to which Dalton had belonged.

Dalton was succeeded by James Prescott Joule as the icon of Mancunian science. Born in 1818, Joule became, by the 1850s, its most visible face. The son of a very successful Salford brewer, he was trained by Dalton in the mid-1830s and did most of his science in the laboratory that he set up in his home. There he developed the ideas and experiments that would eventually lead him to formulate his ideas on the transformation of different forms of energy, including the paddle-wheel experiments for which he became known. 'When I was a boy', Thomson recalled, 'I was introduced by my father to Joule, and when he had gone my father said, "Some day you will be proud to be able to say you have met that gentleman"; and I am' (Thomson, 1936, p. 10).

Joule spent every day from nine to six in the brewery, trading and dealing with his father's business. But his true calling was in his home laboratory, among the electrical and chemical apparatus with which he was experimenting. As soon as he could after his father's death, he sold the brewery and fully embraced his passion for science. Joule's shift from amateur to professional science is paradigmatic of Manchester in the mid-nineteenth century. Two elements played a major role in the change of attitude towards science: first, industry was growing, and its needs were more and more sophisticated. They demanded a more professional approach, far from the idealism and seclusion of men like Dalton. Second, the new bourgeoisie began to feel science was a calling, and not an elegant pastime, and thought they had to become savants of science, as if industrial activity was not *pure* enough. To follow their calling