Chapter 1. The early years in Manchester and Cambridge

1. Manchester

Chimneys. This is the main architectural element that characterizes our 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 their bells. The power of the steam engine, of 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".[1]

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 that the industrial machinery had created: 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, æther, permeate all 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, especially in Chorlton and the lower lying portions of Cheetham Hill;

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."[2]

The ubiquitous chimneys were only the tip of the iceberg of the changes that Manchester underwent in the early 19th 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 by 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 18th century, the Mancunian population was composed of a provincial elite of clergymen, physicians and small-scale traders. By the mid-nineteenth century this elite had been substituted by a growing bourgeoisie of textile industrialists.

Besides the old and new elites, thousands of working-class people piled up in sub-human conditions, in neighbourhoods meant only for them. 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. And it is not the buildings surviving from the old times of Manchester which are to blame for this; 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."[3]

And with this chaotic and highly 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. But besides this, the stream itself is checked every few paces by high weirs, behind which slime and refuse accumulate and rot in thick masses. Above the bridge are tanneries, bone mills, and gasworks, from which all drains and refuse find their way into the Irk, which receives further the contents of all the neighbouring sewers and privies. It may be easily imagined, therefore, what sort of residue the stream deposits. Below the bridge you look upon the piles of debris, the refuse, filth, and offal from the courts on the steep left bank; here each house is packed close behind its neighbour and a piece of each is visible, all black, smoky, crumbling, ancient, with broken panes and window frames. The background is furnished by old barrack-like factory buildings. On the lower right bank stands a long row of houses and mills; the second house being a ruin without a roof, piled with debris; the third stands so low that the lowest floor is uninhabitable, and therefore without windows or doors."[4]

A very significant aspect of the social structure of Manchester was that the division of labour was captured architecturally 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."[5]

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 æther, the social structure of Manchester resembled the relationship between æther 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 æther would permeate the activities of the visible world, being the see for the diverse forms of energy and, in some cases, also the see for the spiritual world. The æther 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.

2. Science in Manchester

The profound changes in the social structure of Manchester triggered in its citizens a transformation in their approach to science. By the end of the 18th century, science was almost non-existent in Manchester. Located between the academic centers of the south (Oxford, Cambridge and London) and the north (Scotland), Manchester was something of a scientific 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 fifty years, however, the panorama had changed completely. Triggered by the new economic situation, science developed in Manchester in the first decades of the 19th 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 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 for the money they made using its resources.

At the turn of the 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 18th century as informal meetings of mainly medical doctors, formally established in 1781.[6] Initially, the number of ordinary members could not exceed fifty, 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*, could deal 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, thus trying to avoid belligerent disputes among the members of the Society. In due course, other scientific institutions would appear 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, and, 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 would have their jobs as doctors, as chemists, as industrialists or as tradesmen, but devote part of their time to the polite cultivation of the sciences or the arts. Among this very amateur and dilettante tradition, and it contrast with it, we find the best known Mancunian natural philosopher, John Dalton, a self-trained natural philosopher, who would become a member of the Society in 1794 and presided over it since 1817 until his death in 1844.

Dalton's biography 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 any bourgeois family. He had been 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 could use 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 August 12th, 1844, an event that was tailored by the local authorities to signal Manchester as a place where first-rate natural philosophy was taking place. 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; and even the roofs of the houses (…) were numerously occupied by parties evidently taking a deep interest in the occasion (…). Indeed, we never saw in this community so general a wearing of mourning attire, crape, &c".[7] Such ostentatious display was only condemned 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 1850's, its most visible face. The son of a very successful Salford brewer, he was trained by Dalton in the mid-1830's and developed 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 the formulation of the transformation of different forms of energy, including the paddle-wheel experiments for which he would become known.

In J.J.'s description, "He was one of those physicists who have, I think, been more plentiful in this country than in any other, who, though not holding any Professorship or other official posts, have devoted themselves to the advancement of science at their own cost and in their own laboratories. (…) When I was a boy 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."[8]

Joule spent every day from nine to six in the brewery, trading, dealing with his father's business. But his true calling was in his home laboratory, among the electrical and chemical apparatus that he was experimenting with. As soon as he could, after his father's death, he sold the brewery and fully embraced his passion for science. Joules' shift from amateur to professional science is paradigmatic of the Manchester in the mid-nineteenth-century. Two elements played a major role in the change of attitude towards science: on the one hand, 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. On the other hand, the new bourgeoisie began to feel science as a calling, and not as an elegant pastime, and thought they had to become savants of science, as if industrial activity was not 'pure' enough. To follow their calling in science, they started as self-trained scientists (forasmuch as many had become self-made men of business). Their entrepreneurial drive included the research and publication of cutting-edge scientific knowledge. In Kargon's words, "this new group, generally from the less prestigious segments of the middle class and sometimes self-made men, were *devotees* of science, who saw science as their 'calling'. Far more serious about the prosecution of scientific activity than their predecessors, the devotees possessed the inspiration proper to a true sense of vocation and were concerned with research at the frontiers of science, with publication, with 'keeping up' with the great practitioners of their specialties, with scientific communication—in short, with man of the things which we associate with the professional pursuit of science. Yet, they were not indeed true professionals. They were, generally, self-taught men, who for a variety of reasons did not care to seek or were not able to obtain careers in science, but earned their livelihoods in business. These businessmen-savants, however, sought their *identity* and (…) even their *status* in the scientific pursuit".[9]

Under Joule's influence, the meetings and the Memoirs of the Lit & Phil also underwent dramatic changes in its scope and content. It became more and more the forum for almost exclusively scientific papers. While, at the beginning of the century, only 50% of papers in the Memoirs were related to the sciences, by the middle of the century, this proportion was 95%, including engineering, which increasingly occupied an important place in the meetings of the Society. The revolution that was taking place in France and Germany, where industry was increasingly collaborating with scientific institutions, was also, although a bit late, coming to Manchester. Joule managed to change the regulations of the Memoirs of the Lit & Phil so that it became a scientific journal *tout court*, including the dates of the reception of manuscripts, de facto excluding all literary articles. In due course, the figure of the devotee was to give way to a totally professional practitioner of science. Contrary to their predecessors, however, this new group of scientists established themselves in Manchester after they were trained in other British and European research centres. Their primary task was to overcome the remnants of amateurism that still pervaded in Manchester and to establish and consolidate scientific institutions in the city.

Many devotees also saw in their scientific endeavours a religious mission. As an example, we can reproduce the notes that Joule had prepared for his speech to the BAAS meeting of 1873: "The great object which natural science has in view is to elevate man in the scale of intellectual creatures by the exercise of the highest faculties of his nature in developing the wonders of the glorious creation. The second and subsidiary object is to promote the well being and comfort of mankind to increase his luxuries. These objects are closely allied and should not be separated. The benefit to be attained is for the entire man, for his soul, his mind, his body. The importance of this object is measured by the importance of that part of human nature which is beneficially affected. The first object is therefore at least as much more important than the second as the intellect is more noble than the body (…). And yet it is evident that an acquaintance with nature's law means no less than an acquaintance with the mind of God therein expressed. This acquaintance brings us nearer to him…".[10]

Dalton and Joule were the two best-known physicists of 19th century Manchester. The first became internationally known for his work in support of the real existence of atoms as corpuscles of matter; the latter became the icon of conservation and transformation of different forms of energy. Both concepts would determine, as we shall see, the scientific career of J.J. Thomson, who would become known for the discovery of the corpuscle-electron while his metaphysical framework was one in which the conservation of energy in the æther played a crucial role. At the very beginning of his memoirs Thomson, a proud Mancunian, pointed at the relevance of these two names in the configuration of science in Manchester: "Manchester has played a prominent part in the history of physical science, for, in it, in the first half of the nineteenth century, Dalton made the experiments which led him to the discovery of the law of multiple proportion in chemical combination, and Joule those which were instrumental in establishing the principle of the Conservation of Energy".[11] J.J. was to think of himself as the one who was able to unify both concepts.

3. Thomson's early days

Joseph John Thomson was born in December 1856 in Cheetham, one of those Manchester suburbs accommodating the middle-class local bourgeoisie of which Engels spoke in his description of the city. His father, Joseph James, was running a modest publishing and bookselling business that three generations earlier one Ebenezer Thomson had founded in Manchester. His mother's name was Emma Swindells. The family would be completed two years later with the birth of J.J.'s only brother, Frederick Vernon.

Little is known about J.J.'s life as a child. The only information we have are the recollections he recorded in his autobiography, written around the age of 80, and which must therefore be taken with a pinch of salt. However, a few points are relevant for a full picture of his biography. Thomson was born into a middle-class family, and educated in a local school. "After going for a year or two to a small school for young boys and girls, kept by two maiden ladies who were friends of my mother, I went to a private day school kept by two brothers named Townsend, at Alms Hill, Cheetham, which was near to where I lived".[12] In the British context, this needs to be emphasized, since it was not uncommon for the offspring of the establishment to be educated, from an early age, in the prestigious boarding public schools scattered all over the country. Education in that kind of establishments was a good starting point from which to gain access to the traditional universities of the country. Thomson was not, therefore, on the right track to start off an academic career.

Later in life, J.J. Thomson became very involved in educational policies, having very well developed views on the way children should be taught. He would look back with a certain sense of nostalgia on some of the aspects of his earlier education, especially the promotion of the use of memory. He was glad to have studied Latin following the Eton Latin Grammar, which was written in verse, so that it was easier to memorize, even though the meaning of words was not always clear. "When I removed my books to Trinity Lodge in 1918, I came across the copy I had used at school, which I had not opened for nearly fifty years, and found that when I once got started I could go on with the 'propria quae maribus' and the 'as in presenti perfectum format in avi', without a slip".[13] In English, they would have to learn by hard fragments of the works of keynote authors such as Shakespeare, Byron and Scott. The syllabus would also include some history and a great deal of arithmetic, which "is an excellent intellectual gymnastic, for it is easy to set simple questions which cannot be solved by rule of thumb, but require thought".[14]

There was almost nothing of the natural sciences at school, except for the collection of some animal and botanical species. Thomson, however, was from a very early age cultivating the Victorian hobby of growing rare species of flowers, "and thought that when I grew up I should like to be a botanist".[15] His son, G.P., would confirm that, besides physics, his father's other passion in Cambridge was his garden.[16] We also know that he possessed a small microscope his father had given him as a present.

Life in the Thomson household seems to have been pleasant, with the normal commodities of a Victorian middle class family. Because of his occupation, J.J.'s father would be relatively well-connected to the intellectual elite of the city. As we saw above, this gave the young J.J. an opportunity to meet, among others, James Joule. Everything changed, however, when Thomson was 16 and his father died. The family had to move to a smaller house, even though they had the help of many friends and acquaintances of the late father.[17] This also meant that the younger brother could not receive the same education J.J. was receiving.

Thomson seems to have been very fond of his brother Fred, who took on the responsibility of looking after their mother when J.J. left for Cambridge. He worked in a local calico merchant company with strong connections in the US. Frederick lived with his mother until her death in 1902 and would meet with J.J. in the summer vacation. He never married. In 1914, he fell seriously ill and J.J. offered that he should move to Cambridge, so that he and his wife could look after him. Fred rented a house near his brother's, until his death three years later, in 1917. The affection of J.J. for his brother was clear in the fact that he "always personally carried a wreath to his grave at Christmas for 21 years, after which he was no longer physically able to do so".[18]

4. Owens College

In spite of his early passion for botany, Thomson, as many young people in Manchester, intended to become an engineer. At the time, there was no such thing as an academic career in engineering and the only way to become one was through hands-on training as an apprentice in an engineering company. However, due to the existence of a long waiting list for such positions, his father decided to send him to Owens College at the age of 13. There, he proved his abilities towards pure science and from there he would eventually move to Trinity College, Cambridge, thanks to a fellowship that he obtained through the encouragement of one of his Owens teachers, Professor Thomas Barker. Actually, Thomson was not the first Owens student to go to Cambridge. The year he started at Owens, John Hopkinson, who had also studied in the college, graduated as senior *wrangler*—the highest honours—in Cambridge, which gave Owens College much prestige.[19]

J.J. was also grateful for the opportunity to go to Owens College, and saw this "accident"—as he called it— as "the most critical event in my life and which determined my career",[20] since the college was a unique institution unparalleled in Britain, both for the scope of its education and for the young age at which students could be admitted.[21] The curriculum at Owens was very different from that in most schools, since it stressed the importance of engineering, experimental physics and chemistry and put less emphasis on the humanities or mathematical physics.[22] The goal of the junior school which J.J. attended was to prepare young students for the formal study of the natural sciences; all with an eye to train scientists who would, directly or indirectly, make a difference to the development of Manchester's scientific and industrial network.

What kind of institution was Owens College? Since the 1830's, a number of influential people had advocated the idea of setting up a university in the industrial and commercial city of Manchester as the necessary culmination of the great development of the metropolis. However, it materialised after the death of John Owens, a wealthy Manchester merchant, in 1846, whose will included a large sum of money to be used for the establishment of a university in Manchester: in 1851 Owens College became a reality, as a college affiliated to the University of London.[23] In the beginning, three were the chairs to be created: one for classics, one for mathematics and natural philosophy, and a third one for mental and moral philosophy and English, following the patterns of traditional universities. There were also part-time appointments in chemistry, in botany, zoology and botany (natural history), in German and in French.

Although initially only a part-time appointment, chemistry would eventually evolve into one of the key areas at Owens College, partly due to the tradition started by Dalton in Manchester, now continued by Joule, but also partly due to the technological needs of many industries in the region. But the establishment of an academically serious department of chemistry was not without obstacle. The first professor, Edward Frankland, had trained with two of the major figures in mid-century chemistry: in Marburg, under Robert W. Bunsen, and in Giessen under Justus Liebig, and he had great expectations to replicate something like Liebig and Bunsen's laboratories in Manchester. Although, at first, he was only a part-time appointment, Frankland managed to organise a laboratory of chemistry and wanted to emphasise the importance of his discipline, not only for practical industrial and medical reasons (which suited potential Manchester students very well) but also for the pursuit of knowledge *per se*. He tried to "recommend the science [of chemistry] for its own intrinsic excellence, for the intellectual delight which every student must find in its pursuit and for the bright glimpses of the Deity which it discloses at every step".[24] But Frankland did not succeed in establishing a research department, partly because the few students he had seemed to be interested only in "testing the 'Soda-ash' and 'Bleaching Powder'",[25] and, tired and disappointed, he decided to leave the college in 1857.

Henry Enfield Roscoe was Frankland's successor in the chair of chemistry. He had also trained with Bunsen and Liebig in Germany, where he learnt of the benefits of research laboratories with links to commercial enterprises. He succeeded in using Frankland's initial impetus to build, over the course of ten years, a school of chemistry with high quality theoretical and experimental training, industrial links and original research. A second chair in chemistry was created in 1874, and Carl Shorlemmer, Roscoe's assistant, born and trained in Germany, was appointed, turning chemistry into a central science at Owens. In his *Recollections* of 1936, Thomson attributed the success of Owens to Roscoe's interest in promoting the education in the sciences, acknowledging that "By the time he left Owens, its Chemical Department had become the best organised and the best equipped in the country, attended by over a hundred students. (…) Roscoe did much by his own personal efforts to promote the application of science to industry. The manufacturers in Lancashire believed in him and were constantly coming to consult him as to the way they should get over difficulties which had cropped up in their work".[26] Roscoe had also become interested, in Germany, in the new science of spectroscopy, a field that proved very successful in the last decades of the nineteenth century. His book on the analysis of spectra turned to be quite influential on the laboratories engaged in spectroscopic techniques, one of which would be the Department of Chemistry in Cambridge from the late 1870's onwards.

But let us go back to 1957. Only six years after the opening of the college, the decline in the number of students proved that an industrial society needed more encouragement for higher education. In Manchester, the offspring of the emergent middle class were mainly interested in practical training and short-term profit, and few people enrolled in fundamental research. Only slowly did the ruling class in Manchester, and the authorities at Owens, realise that the college could neither aspire to compete with the traditional liberal education of Oxford and Cambridge, nor content itself with providing superficial vocational training. The French, and especially the German, scientific institutions were improving their techniques and productivity at a faster pace than the British, thanks to a radically new way of merging academic research and industrial interests,[27] and this was the pattern that Owens College tried to follow since 1857. Also in that year, it was decided to start a junior school associated with the college, the main purpose of which was to get people interested in fundamental research from a younger age. This was the school where J.J. Thomson enrolled in 1870. In 1873, Thomson saw his college move into new buildings on Oxford Street, whose architecture expressed the merging of industry, commerce, training and research.

The academic staff that J.J. found in the junior college was extraordinary for a teenager engineer-to-be: in the chair in Mathematics, Thomas Barker, a senior wrangler and Fellow of Trinity College, Cambridge; in Engineering, Osborne Reynolds, who had also been trained in the Cambridge MT after some apprenticeship in mechanical engineering; in Physics, Balfour Stewart, who came from the Scottish universities of St. Andrews and Edinburgh; and in Chemistry, the aforementioned Roscoe and Schorlemmer. In his autobiography, Thomson would recall the influences that he received from all of them.[28]

From Barker, he received his first instruction in advanced mathematics, which enabled him to learn about the newly introduced quaternionic notation long before he attended Cambridge. Thus, from his early days, Thomson got used to using powerful analytical tools in the solution of physical problems, a tradition that he would certainly develop in the Cambridge MT. Reynolds was a seventh wrangler, but had had a four-year apprenticeship in engineering before going to Cambridge. He was appointed to the newly created chair of engineering at Owens in 1868. Thomson described him in his autobiography as "one of the most original and independent of men, and never did anything or expressed himself like anybody else".[29] Taking notes during his lectures proved to be almost impossible, and the students had to rely on Rankine's textbooks; but it was also evident to them that Reynolds had a very original and independent mind. Since Thomson was initially waiting to be admitted to an apprenticeship in engineering, he spent a lot of time with him in the early years.

But as some historians have emphasised, it was Balfour Stewart who probably most influenced Thomson at Owens College.[30] On the one hand, he introduced J.J. to Maxwell's recent *Treatise on Electricity and Magnetism*, arousing his interest in this science. On the other hand, Stewart was passionate about teaching in the laboratory, and he brought Thomson into hands-on practical research. They spent long hours together, engaged in laboratory work, trying, for instance, to detect a change of weight in chemical reactions. An accident even took place in which Thomson apparently nearly lost his sight.[31] Although Stewart was formally a professor of physics, his research topics were at the boundary between physics and chemistry, which contributed to Thomson's idea that both disciplines were part of a bigger whole. For example, Stewart organised practical courses for three kinds of students, including those "who wish to confine themselves to those branches of Physics most allied to Chemistry".[32] In his study of Thomson's inclination towards chemistry, Sinclair emphasised that Stewart's ideas on the conservation of energy, the constitution of matter, the nature of the æther and of the atoms, etc., were extremely influential on J.J., which explains that he always saw many physical problems "in something of a chemical light".[33]

J.J.'s time in this institution didn't pass unnoticed. His abilities in the sciences granted him several local prizes and scholarships, such as the Ashbury Engineering Scholarship, the Dalton Junior and Senior Mathematical Scholarships and the Engineering Essay Prize,[34] all of which allowed him to continue his studies at Owens after the death of his father. It was also during his time at Owens that he produced his first scientific paper: an experimental work to measure the electrical displacement when two non-conductors were put into contact, which was published in the *Proceedings of the Royal Society*, under the patronage of Balfour Stewart. This paper is only the tip of the iceberg of the uniqueness of J.J.'s training before moving to Cambridge, for it shows that Thomson had a much deeper scientific training, both in mathematical and in experimental physics, than most of his peers in the university. The latter would prove particularly significant after his years as an undergraduate, where all his training would have an exclusively theoretical character, when, after graduating, he decided to complement his training with the acquisition of more experimental skills and, eventually, in his appointment as Cavendish professor.

This particular early training would, however, prove to be a hindrance for entering Cambridge. Encouraged to sit the fellowship examination by Prof. Barker, Thomson failed his first attempt due to his excessively specialised education, which had left some more basic areas unattended. The feedback he got from the examination stated that he "should have done better if, instead of reading the higher subjects in mathematics which were not included in the examination, [he] had concentrated on getting a 'thorough grounding' in the lower ones". The following is Thomson's later ironic description of what this 'thorough grounding' meant: "reading the subjects included in the entrance scholarship examinations over and over again, and doing a great number of trivial examples in them. (…) in some cases the boys, who were to be sent in to compete for entrance scholarships, did little in the two years before the examination but to write out answers to papers set in previous examinations. Under this system the boys get more and more fed-up with mathematics the longer they are at it". As Andrew Warwick showed, this system of training young boys by repetition of case studies and previous examinations in most public schools had its roots in the Cambridge pedagogical system itself.[35] Once again, let us emphasise that Thomson did not arrive in Cambridge from this public school tradition, but from the very unique early training at Owens College.

5. The Unseen Universe

But before going to Cambridge, let us point at another element, certainly present in Thomson's many laboratory hours with Stewart. The mixture of smoke and humidity that permeated the atmosphere in industrial Manchester is a compelling image of the worldview of Victorian scientists. The world of matter was permeated by an entity, the æther, which was the seat of energy and interactions, and the medium for the transmission of waves, especially light. The æther was supposed to be weightless but, at the same time, rigid enough to transmit light waves. The question about the relationship between ordinary matter and æther, between matter and energy, was at its peak in the second half of the nineteenth century. The æther had all the elements of science fiction. Science made its existence necessary; its characteristics made it open to mystery and to all manner of speculation.

Balfour Stewart used this cosmological idea to write, in 1875, together with P.G. Tait, a bestseller on natural theology, called *The Unseen Universe*. Thomson would recall that "Stewart had a strong turn for metaphysics", which would explain the publication of such a book, "which was an attempt to find a physical basis for immortality".[36] Taking æther as the ultimate reality in Nature, Tait and Stewart tried to prove the immortality of the soul and the possible existence of many spiritual entities (but not the existence of a Creator, which they took for granted). The main idea was that the world as we know it, the 'visible universe' as they put it, was only a minor part, contingent and finite in time, of a greater universe, the Unseen Universe, which would include all created things. "We maintain that the visible universe –that is to say the universe of atoms– must have had its origin in time, and that while THE UNIVERSE is, in its widest sense, both eternal and infinite, the universe of atoms certainly cannot have existed from all eternity".[37] In this context, the atoms of matter would be a transient entity: "We are not led to assert the eternity of stuff or matter, for that would denote an unauthorised application to the invisible universe of the experimental law of the conservation of matter which belongs entirely to the present system of things";[38] or, to put it more bluntly, "it appears no less false to pronounce eternal that aggregation we call the atom, than it would be to pronounce eternal that aggregation we call the sun".[39]

Matter was regarded as a non-fundamental entity in the complete universe, but only as an ephemeral phenomenon of the visible universe. Here they introduce a distinction between 'objective' and 'substantive' reality, saying that, while atoms have both types of reality, the unseen world of æther is 'objective' but not 'substantive', an idea that can only be understood in the light of the science of energy that crystallized in the previous decades: "It is only within the last thirty or forty years that there has gradually dawned upon the minds of scientific men the conviction that there is something besides matter or stuff in the physical universe".[40] And, continuing with the same kind of rhetoric, they take energy as this 'something' besides matter: "Taking as our 'system of bodies' the whole physical universe, we now see that (...) energy has as much claim to be regarded as an objective reality as matter itself".[41] In Tait and Stewart's views, there was, however, an ontological asymmetry between matter and æther, for the latter was considered to be more fundamental than the former. This is consistent with such cosmologies as the one implicit in the vortex atom theory of W. Thomson, which assumed atoms to be explainable in terms of vortex in the æther, and which became, in Kragh's expression, a 'theory of everything' in Victorian science.[42] However, they feel that they have to introduce a fundamental change in the conditions of the æther. In W. Thomson's theory, the primordial fluid—the æther—is seen as perfect, and the appearance of the vortex rings as the result of some external (divine) action on it. For Tait and Stewart, this would not accomplish the conditions of a self-sustained Unseen Universe. Thus, they regard the æther as a non-perfect fundamental fluid, in which the vortices appear and disappear as a result of spontaneous fluctuations. In this way, the visible world would be ephemeral "just as the smoke-ring which we develop from air (...) is ephemeral, the only difference being in duration, these lasting only a few seconds, and the others it may be for billions of years".[43]

Tait and Stewart's holistic idea was not at all unique: late nineteenth century science was over-enthusiastic about the possibilities of reducing all knowledge to one metaphysical principle from which all phenomena, including the spiritual, would be deduced.[44] The Unseen Universe is only one example of a "growing commitment to a belief in the uniformity of nature, the restriction of divine action to the creation of the universe, the rejection of suppositions of divine interventions to explain apparent discontinuities in the natural world, and the separation of the natural and the supernatural".[45] The interest of this book, as far as J.J. Thomson is concerned, resides not only in the fact that it was a best-seller among those with interests in science and natural philosophy,[46] but mainly in the fact that Stewart was writing this book precisely in the years when J.J. spent long hours in the laboratory under his guidance and this must have certainly exerted a direct influence on him.[47] As Davis and Falconer stated, Thomson received from Stewart a thorough grounding in the prevalent Victorian method of reasoning by analogy and in æther physics.[48]

But not only that. In a later chapter we shall find Thomson directly involved in the Society for Psychical Research, a society devoted to the scientific study of paranormal phenomena, something to which certain physics of the æther was particularly prone. For the time being, it suffices to quote from a public lecture he gave in his hometown, in 1907, in which he would explain the relationship between æther and matter, between electricity and mechanics, in a language suited to his audience, mixing the physical, the mercantile and the mysterious: "The study of the problems brought before us by recent investigations leads us to the conclusion that ordinary material systems must be connected with invisible systems which possess mass whenever the material systems contain electrical charges. If we regard all matter as satisfying this condition we are led to the conclusion that the invisible universe –the æther—is to a large extent the workshop of the material universe, and that the phenomena of nature as we see them are fabrics woven in the looms of this unseen universe".[49]

6. Undergraduate in Cambridge

Whereas Owens College was a new institution born in a lively city and promoted by the same entrepreneurial bourgeoisie that was developing Manchester itself, Cambridge was a completely different world. The model of science in that ancient and aristocratic university was mathematical physics, the teaching of which was organised around the *Mathematical Tripos*. Eminent Victorian scientists such as John Herschel, William Whewell, George G. Stokes, William Thomson, Peter G. Tait and James C. Maxwell had all been MT students. Without completely denying the importance of observation and experimentation, the ideal science in Cambridge was one in which data and theories had achieved a complete mathematical formulation, which could then be turned into the starting-point for the solution to new problems. Whewell, the influential master of Trinity College, worked to emphasise the role of mathematical training in Cambridge in the mid-nineteenth century. As he put it in 1837, the progress of the sciences "depends on the distinctness of certain fundamental ideas; and these ideas, being first clearly brought into view by the genius of great discoverers, become afterwards the inheritance of all who thoroughly acquire the knowledge which is thus made accessible".[50] The role of university training in the sciences was, from this perspective, the transmission of fixed principles or fundamental ideas, and the usual work of scientists would be to deductively develop new consequences of such principles by means of reasoning and mathematical work.[51] With this model in mind, the experimental sciences appeared as a kind of second-class knowledge. They were provisional and particular and they lacked the rigour of mathematical formulation.

With the increasing specialization of the different sciences, however, Cambridge accepted the need to create a new *tripos* of experimental science, and, in 1851, the *Natural Science Tripos* was established. The chairs involved in this tripos were, at first, chemistry, experimental natural philosophy, mineralogy, geology, comparative anatomy, physiology and botany. Physics, being at the core of the MT, was not, at the beginning, part of the NST, thus incarnating the Whewellian distinction between adult and under-aged sciences. Only with the establishment of the Cavendish Laboratory did experimental physics enter the NST, and, when Thomson went to Cambridge in 1876, physics was being taught, although from radically different perspectives, in both the MT and the NST. However, it was still the case that the MT had a much greater prestige in Cambridge, and it was the one that promising students like J.J. were expected to follow.[52]

Thomson arrived in Cambridge in October 1876 and, as he put it in his autobiography, "'kept' every term since then, and [was] in residence for some part of each Long Vacation",[53] which means that he never left Cambridge for more than a few weeks ever since his arrival at the age of 19. After his first failed attempt to enter Cambridge, Thomson prepared himself for the examination and he sat again, on April 18, 1876, for the examination to get a fellowship in the most prestigious of Cambridge institutions: Trinity College.[54] Only the wealthiest colleges in Cambridge could afford to offer some scholarships for brilliant students with meagre financial resources like Thomson. The exam consisted of two papers "confined to questions in Arithmetic, Geometry, Algebra, Trigonometry, Conic sections treated both geometrically and analytically, the Elements of the Differential Calculus, and Mechanics as far as the Dynamics of a particle included",[55] some of which involved a serious mastery of advanced mathematics. He was one of six candidates to win a 'Minor Scholarship', with a value of £75 a year. Just to give an idea of the number of students awarded a scholarship, in the year 1876, there were only 12 scholars out of 167 matriculated students in Trinity College.[56] The following year he sat for a 'Foundation Scholarship', a fellowship open to undergraduates of the college, which increased his income to £100 a year, as well as his prestige in the college.

Life as an undergraduate in Cambridge was, and in some respects still is, a unique experience. Even though the introduction of the new *triposes*, with tighter syllabuses, was changing the face the university, the long tradition of liberal education made itself felt very prominently. Cambridge was not only a place of academic learning: it was a factory of mass production of gentlemen to the service of the Empire. That is why the strictly academic education went hand in hand with a very intense social life which included college celebrations, sports tournaments, religious events, and a wide range of activities in which the young men developed a particular *savoir faire* that turned them into exemplary Victorians. Thomson found this new world attractive and he didn't seem to have many problems fitting in. At the time, the college fellowships provided their recipients with enough money to spend entertaining their friends and colleagues in college, something that, in time, he would consider to be essential to any Cambridge student.

Thomson described his days as an undergraduate as "very pleasant but uneventful",[57] and, with a closer look at his recollections, we can infer that this means he was very much work-oriented and not specially good at those activities undergraduates tended to value most: sports. The main games in those days were cricket and football, and rowing was just becoming increasingly popular. However, Thomson, like "The ordinary reading man who was not particularly good at games, had not much chance of playing either cricket or football (…)—there was no room for the 'rabbits'".[58] J.J., like most of his peers would get the needed physical exercise by taking walks: "Between 2 and 4 in the afternoon, streams of undergraduates, two and two, might be seen on all the roads within three or four miles of Cambridge (…). On Sundays many went further afield and walked for five or six hours". Occasionally he would play a tennis match or some golf, sports that "only require two players and for which it is generally possible to find an opponent nearly as bad as yourself so that you don't feel you are spoiling anyone's game".[59] The confidence and brilliancy in his academic career would certainly fail him in more prosaic activities.

Chapel assistance was compulsory in certain festivities and events. It is not easy to assess J.J.'s attitude towards religion. He came from a normal Anglican family, and there is no reason to assume a rejection of religious practice, nor an excessive religious fanaticism. As an example, in his autobiography, he would jokingly tell how difficult it was, at times, to attend the 7.30 a.m. service, since "though we got up early it was not quite early enough, and the Chapel doors were shut before we could reach them".[60] As for amusements in Cambridge, there was not much to do in the town. The only theatre was open solely during Vacation, and the amateur drama society of the university performed two plays per year. As for dancing, the only such event was the May Week, partly due to the extremely low numbers of female students around the university. These arrangements meant that a student could seriously concentrate in his work, rather than getting distracted by other activities.

7. Second wrangler in the Mathematical Tripos

The central figure in the education of a Cambridge student was the college tutor. He was responsible for guiding the student during his undergraduate years, looking after his welfare in all the aspects of his life in the university. The long tradition of liberal education in Cambridge meant that there was no fixed syllabus, but the students were free to choose the courses and lectures they wanted to attend. The tutor was responsible for orienting the student in his choices among a sea of college, intercollegiate and departmental lectures. Thomson's tutor, a Mr. J.M. Image, was a classicist, with little idea about the intricacies of mathematics, and thus Thomson could choose the lectures that most suited his interests and needs, and to avoid some lecturers, "the dullness of some of [which] can hardly be imagined".[61]

In Victorian Cambridge, however, candidates for the higher ranks in the MT underwent an intensive training under the guidance of an independent coach, who made sure that his students read all the subjects included in the examinations, something not easy considering the large number of subjects and the limited time in which to study them. Thomson, like many of his contemporaries, was coached by Edward Routh who, without being a professor at the university, was perhaps the most influential Cambridge mathematician of his time. The system used by the coaches consisted in combining their lectures with very competitive weekly targets in solving exam problems from previous years. The training also included time constraints: "one week we could take as much time as we pleased in solving the problems, the next we were expected to do them in three hours, the time allowed for such a paper in the tripos. We sent the papers in at the end of the week, and on the next Monday morning a complete solution of the paper in Routh's handwriting was placed in the pupil's room, together with a list of the marks each pupil had obtained. This introduced a sporting element, and made us take more trouble over them than we should otherwise have done".[62] This system of coaching created an army of mathematicians who were convinced that any problem in physics could, in the end, be studied using the powerful tools of modern mathematical analysis. The problem-solving pedagogy meant that the students only thought on how to solve the problem, not on whether the problem was soluble or not.

Routh had been senior wrangler in 1854, beating James Clerk Maxwell in the rankings. The following year, he was elected to a fellowship and lectureship in Peterhouse (one of the colleges in Cambridge), and, from that position, he became the most successful of Cambridge coaches: of the 990 wranglers who graduated between 1862 and 1888, almost half were coached by Routh (including 26 senior wranglers), while between 1865 and 1888, 80 percent of the top three wranglers were his pupils.[63] This made him the most influential mathematician in Cambridge, far beyond the impact any lecturer would have on his students. Thomson kept a vivid recollection of Routh's lifestyle: "The regularity of Routh's life was almost incredible; his occupation during term time could be expressed as a mathematical function of the time which had only one solution. I believe one who had attended his lectures could have told what he had been lecturing upon at a particular hour, and on a particular day, over a period of twenty-five years. The fact that year after year he gave the same lectures at the same time did not make him stale as it would most people. He might, as far as one could judge from his manner, have been delivering each lecture for the first time. His way of taking exercise was as regular as his lectures: every fine afternoon he started at the same time for a walk along the Trumpington Road; went the same distance out, turned and came back. His regularity was not, as might perhaps have been expected, accompanied by formal and stereotyped manners; these were very simple and kindly and we were all very fond of him".[64]

Historian Andrew Warwick has analysed the pedagogical tradition in Cambridge and the particular role played by Maxwell's *Treatise of Electricity and Magnetism*. Published in 1873, just after his appointment as the first Cavendish Professor, the

Treatise was intended as a compendium of theoretical and experimental approaches to electricity and magnetism, and included Maxwell's new views on the field. The *Treatise* was, thus, thought as a textbook to aid him in his professorial role. In the hands of other people, however, making sense of the *Treatise* proved a difficult task, since there was a lot of tacit knowledge, which most readers would not have. That is why Cambridge students in the late 1870's were in a privileged milieu to understand Maxwell's work even though, when doing so, they developed one particular understanding of it. "The collective understanding of electromagnetic field theory that emerged in Cambridge circa 1880 was shaped by a combination of the problem-solving approach (…) and discussions at the intercollegiate lectures on the *Treatise* held at Trinity College by W.D. Niven".[65] Outsiders, on the other hand, lacking the pedagogical tools of Cambridge undergraduates, would find it very difficult to make sense of the *Treatise*. An example of this is the speed with which Thomson was able to develop important consequences of Maxwell's electromagnetic theory: "Where men like Heaviside and Fitzgerald had taken years of private study to begin offering their own original contributions, Thomson wrote two important papers on electromagnetic theory within months of graduating while working simultaneously on several other projects".[66]

Together with Routh, the aforementioned W.D. Niven was the second most influential person in Thomson's education in Cambridge. Niven had been third wrangler in the MT in 1866 and, in 1874, was invited to return to Trinity College as a lecturer in mathematics. In Cambridge he became a close friend of Maxwell, to the extent of considering himself his intellectual heir, especially after Maxwell's untimely death in 1879. Niven was responsible for the second edition of the *Treatise* as well as for the edition of the two volumes of Maxwell's scientific papers.[67] Niven became the person to meet in order to understand the *Treatise*. His intercollegiate lectures, attended by ambitious undergraduates and new wranglers, became the forum of discussion of the new ideas.[68] Thomson would remember that the importance of Niven's lectures resided not so much in its clarity but in his enthusiasm: "Niven was not a fluent lecturer nor was his meaning always clear, but he was profoundly convinced of the importance of Maxwell's views and enthusiastic about them; he managed to impart his enthusiasm to the class, and if we could not quite understand what he said about certain points, we were sure that these were important and that we must in some way or other get to understand them. This set us thinking about them and reading and re-reading Maxwell's book, which itself was not always clear. This was an excellent education and we got a much better grip of the subject, and greater interest in it, than we should have got if the question had seemed so clear to us in the lecture that we need not think further about it".[69] William Niven became a life-long friend of J.J.: he "was one of the best and kindest friends I ever had; he was very kind to me from the time I came up as a freshman. He often asked me to go walks with him. I went very often to his rooms and, through him, I got to know many of the Fellows of the College". One sign of this close and long lasting friendship with Niven is that he eventually became J.J.'s first son's godfather.

Among the other lecturers in his undergraduate years, Thomson would recall with particular affection J.W.L. Glaisher, whose lectures where "the most interesting I ever attended",[70] not only for his clarity and enthusiasm in pure mathematics, but also for the amusing anecdotes he used to tell during his lectures. Other lecturers were Professors A. Cayley, J.C. Adams and G.G. Stokes. The first was significant for the particular way he had to solve problems: "he did not seem to trouble much about choosing the best method, but took the first that came to his mind. This led to analytical expressions which seemed hopelessly complicated and uncouth. Cayley, however, never seemed disconcerted but went steadily on, and in a few lines had changed the shapeless mass of symbols into beautifully symmetrical expressions, and the problem was solved".[71] Thomson saw this as a good lesson not to be afraid of complicated mathematical expressions. By contrast, Adams lectures were magnificently clear and ordered, since he "carried the feelings of an artist into his mathematics, and a demonstration had to be elegant as well as sound before he was satisfied".[72] His only problem was that he read his lectures, which made them less appealing. Finally, Stokes' lectures were Thomson's favourites: "for clearness of exposition, beauty and aptness of the experiments, I have never heard their equal".[73]

The world of the *Treatise* was the world of æther. In the book, "an attempt [was] made to explain electromagnetic phenomena by means of mechanical action transmitted from one body to another by means of a medium occupying the space between them".[74] The existence of the æther was technically only a hypothesis, but one that could be supported by different and independent theories. Light and electromagnetism, so far independent phenomena, were united under the same explanatory framework. Light was, in Maxwell's theories, a manifestation of electromagnetic waves. This unification was a boost for the existence of an æther that had first been postulated to account for the transmission of light. In Maxwell's words, "if the study of two different branches of science has independently suggested the idea of a medium, and if the properties that must be attributed to the medium in order to account for the electromagnetic phenomena are of the same kind as those which we attribute to the luminiferous æther in order to account for the phenomena of light, the evidence for the physical existence of the medium will be considerably strengthened".[75] The fact that electrical and optical evidence independently supported the hypothesis of an æther produced in Maxwell and those around him a "conviction of the reality of the medium similar to that which we obtain, in the case of other kinds of matter, from the combined evidence of the senses".[76]

Electromagnetic phenomena could be explained by considering the dynamical properties of the all-pervading ether, that is, assuming the æther to be continuous medium in which kinetic and potential energy could be stored. The transmission of this energy through the ether, consistent with the principle of conservation of energy, would account for all the electromagnetic processes. Even though Maxwell had a particular view on the structure of the ether, imagining it in terms of hexagonal cog-wheels in motion, this structure was not important to account for the electromagnetic phenomena. The only properties he needed the æther to have were those of a continuous medium, a fluid.[77] The equations valid in hydrodynamics would, then, be valid in describing the ether, in the same way that one does not need to assume liquids as composed of atoms in order to discuss the hydrodynamic properties of fluids.

The last sentence of the two-volume opus makes it clear that his primary goal in the *Treatise* was to understand the mechanisms by which the æther acts: "all these theories lead to the conception of a medium in which the propagation takes place, and if we admit this medium as an hypothesis, I think it ought to occupy a prominent place in our investigations, and that we ought to endeavour to construct a mental representation of all the details of its action, and this has been my constant aim in this treatise".[78] Thomson's education was, as any MT student in the 1870s, deeply imbued by this metaphysical worldview.

Overall, the education in physics received in the Mathematical Tripos was fundamentally theoretical. In J.J.'s times, students for the MT were not expected to attend any demonstrations in the new Cavendish Laboratory. As a matter of fact, there had been attempts to include questions in the exams the answer of which was only possible if one had some experimental knowledge; but the repeated failure to engage students and coaches alike in this project meant that such questions were systematically left unanswered by all students. By the late 1870s, "it had become clear that mathematics students could grasp the principles of, say, Wheatstone's Bridge and its application to practical electrical measurements without actually witnessing the instrument in action".[79] That explains why, in his undergraduate years, Thomson never entered the Cavendish or even met Maxwell.

Nevertheless, Thomson did not see this almost exclusively mathematical training as a handicap for his career as a physicist: "I probably read more pure mathematics than I should have done if I had taken my degree a few years later. I have found this of great value (*c'est le premier pas qui coûte*), and it is a much less formidable task for the physicist, who finds that his researches require a knowledge of the highest parts of some branch of pure mathematics, to get this if he has already broken the ice, than if he has to start *ab initio*".[80]

Finally, in January 1880, Thomson sat for the MT exams. The intensity of the examination days was beyond limits. Even such a relaxed and self-confident man as J.J. would have those days deeply engraved in his memory: "The thing about it which remains most clearly in my memory is that I suffered from a bad attack of insomnia during the last five days [of the exams], and got very little sleep. Insomnia is even more unpleasant in Cambridge than in most other places, for since several clocks chime each quarter of an hour you know exactly how much sleep you have lost, and this makes you lose more".[81] In spite of this difficulty, Thomson performed very well and ended up second wrangler, Joseph Larmor topping the list. The total number of people awarded honours was 99.

[1] Léon Fraucher, Manchester in 1844, (London: 1844), p. 16. Quoted in Kargon, Victorian Manchester, p. 2.

[2] Friedrich Engels, *The Condition of the Working-Class in England in 1844*, in http://www.marxists.org/archive/marx/works/1845/condition-working-class/ch04.htm.

[3] Friedrich Engels, *The Condition of the Working-Class in England in 1844*, in http://www.marxists.org/archive/marx/works/1845/condition-working-class/ch04.htm.

[4] Friedrich Engels, *The Condition of the Working-Class in England in 1844*, in http://www.marxists.org/archive/marx/works/1845/condition-working-class/ch04.htm.

[5] Friedrich Engels, *The Condition of the Working-Class in England in 1844*, in http://www.marxists.org/archive/marx/works/1845/condition-working-class/ch04.htm.

[6] See Cardwell, D. Two Centuries of the Manchester Lit & Phil, p. 122, in The Development… XVI

[7] The Manchester Guardian, Wednesday 14th August, 1844.

[8] Recollections… p. 10.

[9] Kargon, p. 35.

[10] James Joule Manuscripts, quoted in Kargon, p. 55-56.

[11] Recollections, p. 7.

[12] Recollections, p. 2

[13] Recollections, p. 3.

[14] Recollections, p. 4.

[15] Recollections, p. 6.

[16] G.P. Autobiography, Trinity College

[17] The new address was 11 Egerton Terrace, Fallowfield. Cfr. Rayleigh, p. 3.

[18] Rayleigh, p. 185.

[19] Recollections, p. 2. This seems to have been the main arguments used to convince his father to send the young J.J. to Owens College.

[20] Recollections, p. 2

[21] Actually, JJ claimed that "indeed the authorities at Owens College thought my admission such a scandal—I expect they feared that students would soon be coming in perambulators—that they passed regulations raising the minimum age for admission, so that such a catastrophe should not happen again". (Recollections, p. 2)

[22] R.H. Kargon, *Science in Victorian Manchester* (Manchester, 1977), 157-96.

[23] See Ibid.

[24] E. Frankland, "On the educational and commercial utility of chemistry", cited in Kargon, *Science in Victorian Manchester* (ref. 10), 159.

[25] Frankland to Bunsen, 3 March 1856, quoted in Kargon, 1977, p. 164.

[26] J.J. Thomson, *Recollections and reflections* (London, 1936), 29.

[27] See F.M. Turner, *Contesting cultural authority: essays in Victorian intellectual life* (Cambridge, 1993); R. Sviedrys, "The rise of physics laboratories in Britain", *Historical Studies in the Physical*

Sciences, vii (1976), 405-36; G. Gooday, “Precision measurement and the genesis of physics teaching”, *British Journal for the History of Science*, xxiii (1990), 25-51.

[28] Ibid., 13-33.

[29] Ibid., 15.

[30] E.A. Davis and I. Falconer, *J.J. Thomson and the discovery of the electron* (London, 1997), 6. See also Chayut, “J.J. Thomson: The discovery…” (ref. 8); and J.G. Crowther, *The Cavendish Laboratory 1874-1974* (London, 1974), 114: “In some ways he owed more to Balfour Stewart and Manchester [than to Maxwell]. His own greatest discoveries were to come more from the mode of thought of his Applications of Dynamics to Physics and Chemistry, inspired by the ideas of Balfour Stewart, who had concentrated more on atoms and molecules, and their dissociation. J.J. was in Cambridge for four years without getting to know Maxwell”.

[31] Thomson, *Recollections* (ref. 13), 20: “Balfour Stewart was much interested in the question as to whether there is any change in weight when substances combine chemically. When I was helping him with some experiments on the combination of mercury and iodine these substances combined with such a violence that the flask they were in exploded in my face and I nearly lost the use of both eyes”.

[32] Kargon, *Science in Victorian Manchester* (ref. 10), 216 and Chayut, “J.J. Thomson: The discovery…” (ref. 8), 532.

[33] Sinclair, “J.J. Thomson and the chemical atom …” (ref. 6), 91.

[34] Rayleigh, p. 6.

[35] Warwick, esp. 254-64.

[36] (Thomson 1936, 22)

[37] (Stewart and Tait 1884, 9)

[38] (Stewart and Tait 1884, vii)

[39] (Stewart and Tait 1884, xv)

[40] (Stewart and Tait 1884, 100)

[41] (Stewart and Tait 1884, 114-115)

[42] See Kragh (2002). More on this in the following chapter.

[43] (Stewart and Tait 1884, 157)

[44] See C. Smith, *The science of energy* (London 1998), esp. chapters 7 and 10; P. Harman, *Energy, force and matter. Conceptual development of nineteenth-century physics* (Cambridge 1982), esp. chapter 3. See also R. Noakes, “Ethers, religion and politics in late-Victorian physics: beyond the Wynne thesis”, *History of Science*, xliii (2005), 415-55. See G. Myers, “Nineteenth-Century Popularizations of Thermodynamics and the Rhetoric of Social Prophecy”, in P. Brantinger, ed., Energy and Entropy. Science and Culture in Victorian Britain, Indiana Univ Press, 1989.

[45] Heimann (1972), p. 75

[46] See Heimann (1972).

[47] See Sinclair (1987), 90.

[48] Davis and Falconer (1997), 6. See also Chayut (1991).

[49] JJ Thomson, *"On the light thrown by recent investigations on Electricity on the relation between Matter and Ether"* The Adamson Lecture Delivered at the University of Manchester on November 4, 1907, p. 21

[50] W. Whewell, *On the Principles of English University Education* (London, 1837), 20.

[51] See P. Williams, "Passing the torch: Whewell's philosophy and the principles of English university education", in M. Fisch and S. Schaffer, eds., *William Whewell: A composite portrait* (Oxford, 1990), 117-47.

[52] G.K. Roberts, "The liberally-educated chemist: Chemistry in the Cambridge Natural Science Tripos, 1851-1914", *Historical Studies in the Physical Sciences*, xi (1989), 157-83.

[53] Recollections, p. 34.

[54] CHECK AND INSERT WHERE IT SAYS THAT HE HAD TO TAKE THE EXAM TWICE. THE REASON: THE PECULIARITY OF OWENS COLLEGE TRAINING.

[55] CUR, October, 19, 1875, p. 45

[56] Figures in the CUR, Nov 21, 1876.

[57] Reclloections, p. 52.

[58] Recollections, p. 66.

[59] Recollections, p. 67.

[60] Recollections, p. 53.

[61] Recollections, p. 44.

[62] Recollections, p. 38.

[63] Cfr. Warwick, p. 233.

[64] Recollections, pp. 40-41.

[65] Warwick, Masters, p. 291

[66] Warwick, *Masters* (ref. 9), 343. The papers of Thomson alluded to are J.J. Thomson, "On Maxwell's theory of light", *Philosophical Magazine*, ix (1880), 284-91; "On the electric and magnetic effects produced by the motion of electrified bodies", *Philosophical Magazine*, xi (1881), 229-49.

[67] Niven, The Scientific Papers of James Clerk Maxwell, Cambridge 1890.

[68] Warwick, p. 317.

[69] Recollections, p. 42-43

[70] Recollections, p. 44.

[71] Recollections, p. 47.

[72] Recollections, p. 47.

[73] Recollections, p. 48.

[74] Maxwell, Treatise, vol. 2, p. 430, § 781.

[75] Maxwell, Treatise, vol. 2, p. 430, § 781.

[76] Maxwell, Treatise, vol. 2, p. 430, § 781.

[77] Reference to Buchwald

[78] Maxwell, Treatise, vol. 2, p. 493, § 866.

[79] Warwick, p. 315.

[80] Recollections, p. 39.

[81] Recollections, p. 63