THE LIFE AND WORK OF CHARLES TOMLINSON FRS: A CAREER IN VICTORIAN SCIENCE AND TECHNOLOGY

by

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SUMMARY

Charles Tomlinson (1808–97) was an exceptionally versatile scientist of the Victorian era, who, in a long career as an educator, encyclopaedist and researcher contributed significantly to the advancement of science and technology. By his prolific authorship of some 50 books and 100 published papers and notes, he promoted the dissemination of scientific information, both to professionals and to a wider public that was beginning to appreciate the powerful influence of technology on the wealth and well-being of society. In his magnificent *Cyclopaedia of the useful arts*, he set a monument to the contemporary state of science, technology and the manufactures. His researches in the field of chemical physics, especially concerned with the phenomena of surface tension, supersaturation and meteorology, were recognized by his election as a Fellow of The Royal Society.

Keywords: Charles Tomlinson FRS; meteorology; supersaturation; surface tension phenomena; Victorian science and technology

INTRODUCTION

Charles Tomlinson (1808–97) (figure 1), a notable publicist, educator and investigator in the field of science and technology, was a well-known and respected figure on the London scientific scene throughout the long Victorian era. He had risen, by his talents, his passion for science and unremitting devotion to study, from humble beginnings to a reputable position in the capital’s scientific establishment. His massive technical *Cyclopaedia*, the product of his single-handed effort, survives as a permanent record of the progressive and enterprising technical spirit of the age. Tomlinson’s numerous introductory treatises on the various branches of physics, and his extensive teaching activities, were significant contributions to the dissemination of scientific knowledge, and no doubt encouraged many a young person to embark on a technical career. His original researches illuminated several fundamental questions in the borderland between physics and chemistry, and found recognition in his election as a Fellow of The Royal Society.

Tomlinson was a gifted linguist, and translated Italian Renaissance poetry with almost scientific precision into metric English. His appointment as the first Dante Lecturer at
University College London in 1878–80 was an unusual distinction for a man of a scientific rather than literary background. Tomlinson’s high standing in contemporary opinion is attested by the inclusion, in his lifetime, of a biographical sketch in Allen’s authoritative *Biograph and review*.¹ This provided the material for the standard entry in the *Dictionary of national biography*,² and the eventual obituaries.³ His niece, who presided over his household during his declining years, remembered him in an affectionate memoir,⁴ which focused chiefly on his domestic and social life and on his personality. Thereafter, for the next 100 years, Tomlinson’s name has all but vanished from notice. The present account highlights the achievements of his long career, which incidentally reflects many aspects of the fabric of science of his time.
Charles Tomlinson, the younger of two brothers, was born in London on 27 November 1808 into modest circumstances. His father, induced by adversity, enlisted in the Army and died on the passage to India, where his regiment was posted after service in the Low Countries. His widow raised her two boys as best she could, but their schooling, indifferent as it was, ceased when at the age of 12 years they had to find employment. Charles spent the next 10 years in uncongenial clerical posts, but with his keen thirst for knowledge he continued to broaden his education, especially in the sciences, attending Dr Birkbeck’s evening courses at the recently established (1825) London Mechanics’ Institution, and Dr Turner’s chemical lectures at University College London.

Charles’s elder brother, Lewis, worked for several years as an assistant schoolmaster and was eventually enabled with the support of friends to take up a Bible clerkship at Wadham College, Oxford, where he graduated BA in 1829. He obtained a teaching curacy and invited Charles to join him in his educational work: the brothers opened a day-school for boys in Salisbury, which proved a success, due in no small measure to Charles’s ability to include science subjects in the curriculum, an unusual and welcome novelty in a provincial town at the time. Tomlinson’s additional evening lectures, illustrated with experiments, were highly popular with wider audiences.

Side by side with his teaching and the pursuit of some modest research projects, Tomlinson began to publish articles on a variety of scientific topics in such periodicals as the Magazine of Popular Science and the Saturday Magazine. He subsequently incorporated some of this material in his Manual of natural philosophy (1838), in which the science of physics was presented in a novel and attractive way: choosing twelve ‘philosophical instruments’ for as many divisions of his book, Tomlinson wove about each of them a lucid account of the branch of physics that it represented. The chapter on the compass, for example, introduced the principles of magnetism, and described the use of the instrument in navigation, including much up-to-date technical information not found in conventional textbooks. Chapters on the thermometer, barometer, hygrometer, prism, and so on, were similarly structured. In spite of its familiar approach, the treatment adhered to strict scientific principles and demanded serious study on the part of the reader.

The success of the Manual proved a turning point in Tomlinson’s career: its enterprising publisher, J. W. Parker, recognizing the author’s obvious talent for scientific writing, enlisted his services in his expanding educational publishing ventures. Returning to London in 1842, Tomlinson was immediately brought into close contact with notable men of science. He assisted W. Snow Harris in his promotion of the improved lightning conductor, including its use in the protection of the ships of the Navy. He collaborated with W. T. Brande in the revision of the sixth edition (1848) of his well-known Manual of chemistry, and with W. A. Miller, professor of chemistry at King’s College, in the preparation of a new edition of Daniell’s Meteorology, which had been interrupted by the author’s death. This project was the origin of Tomlinson’s lifelong keen interest in meteorology; he wrote in quick succession several popular treatises on meteorological subjects, which correlated the phenomena of weather with their underlying scientific
principles. He also shared much of the labour of revising and preparing for the press Miller’s comprehensive textbook of chemistry; his faithful assistance was freely acknowledged in the author’s preface and cemented a firm friendship between the two men.

By such contacts with King’s College and his association with Parker’s publishing house, itself of high repute within the college, Tomlinson’s merits were brought to the notice of its authorities and led, in 1856, to his appointment as Lecturer in Science at King’s College School, then conducted within the college precincts in the Strand. Here for the next 12 years he enjoyed a stimulating environment as an instructor and researcher. His courses on natural philosophy and chemistry were evidently highly successful, as it seems from the college’s Annual Report for 1858:

Experience has shown that [these lectures] serve to fill a great desideratum in our system of modern education. … The Council desire to express their sense of Mr Tomlinson’s services, not less in the happy selection of his subjects, than in the judicious and systematic mode of teaching, which he has adopted in elucidating the great laws of nature and the phenomena of everyday life.

After his retirement in 1868, Tomlinson continued to be invited to give specific talks or to organize courses in various venues. His lectures, invariably enlivened with demonstration experiments, were described as models of clarity and were carefully attuned to the level and needs of his audience. He acted as examiner in physics at the Birkbeck Institution and delivered, in 1883, the Inaugural Address of its 61st Session, which marked its impending move to Breams Buildings, Chancery Lane. On this occasion he addressed his audience from the rostrum of the Old Lecture Room, where as an eager young pupil he had sat on a bench.

THE CYCLOPAEDIA

The most ambitious and successful project of Tomlinson’s writing career was his Cyclopaedia of useful arts, which, as its full title proclaimed, surveyed the entire range of the physical, chemical and engineering disciplines, both pure and applied. Its lavishly illustrated text emphasized the usefulness of science and technology and their beneficent influence on the prosperity, comfort and health of the nation, reflecting the optimistic and enterprising attitude of mid-Victorian mercantile society. The work was intended to appeal to an intelligent general public that had but lately marvelled at the wonders of the Great Exhibition of 1851, but it was also to provide ‘a reliable book of reference, and an indispensable companion of the manufacturer, the miner, the chemist, the engineer, and the scientific workman’.

Tomlinson appears merely as ‘Editor’ on the title page of the work, but was in fact its sole creator. He produced lucid memoirs on a vast variety of subjects, based on the best authorities as well as his first-hand knowledge of current industrial practice. This he acquired by assiduous personal inspection of processes and machinery in actual use, a fact reflected in his repeated acknowledgement of the courtesy and cooperation of proprietors who had afforded him access to their plants. A most important source of technical information, especially in the field of mechanical engineering, was the Great Exhibition, which, on his own testimony, Tomlinson visited no less than 50 times.
Most of the entries were concise, but topics of major economic or public interest (such as the metallurgy of iron and steel, bleaching, dyeing, the steam engine and the electric telegraph) were the subject of veritable minor treatises, covering 15–30 or more closely printed pages. As an introductory essay, Tomlinson wrote an elaborate account of the Great Exhibition—in fact a full-length book in its own right—based partly on the mass of ephemeral guidebooks, catalogues and reports that had mushroomed around the enterprise, but chiefly on his personal impressions.

The undoubted success of the *Cyclopaedia* was due in no small measure to the ample resources of its eminent publishers, Messrs Virtue & Co., the house renowned for its lavishly illustrated books on art and travel. In accordance with contemporary usage, the *Cyclopaedia* first appeared in fortnightly parts (1852–54), which were subsequently gathered into two massive volumes, illustrated with 40 full-page steel engravings and 2477 woodcuts in the text, many of them the work of leading draughtsmen and engravers of the day. When after 10 years a second edition was called for, Tomlinson produced an enlarged work (1861–66) by the addition of a supplementary third volume. The introductory essay was now devoted to a history of invention, as illustrated by the art of printing. The new edition contained the only contribution from a pen other than Tomlinson’s, namely a monograph on coining, by a specialist of the Royal Mint.

Tomlinson’s powers as an encyclopaedist found further outlet in his contributions to the eighth edition of the *Encyclopaedia Britannica* and to the *English cyclopaedia*. At the same time, his output of educational texts continued undiminished. Elementary though these concise manuals were, they were designed to be aids to serious study, as Tomlinson emphasized in one of his prefaces:

> If scientific men are disposed to prepare popular treatises … and intelligent publishers to issue them at a price to bring them within the reach of all, it is not too much to expect the cooperation of the reader, who must be prepared to … study the work, not merely to glance over its pages. If he finds it difficult on a first reading, let him give it a second, or a third, and we may venture to assure him that his labour will not be misapplied.

A typical example of Tomlinson’s quick grasp of the working of complicated mechanical contrivances and his power of clear exposition of their intricacies is his volume on the *Construction of locks*, in which he explained in minute detail the mechanism of conventional as well as the Bramah and American locks, and the precise function of their individual parts.

**METEOROLOGY**

Tomlinson’s lifelong fascination with meteorology attracted him again and again to this favourite though perplexing subject. His early association with W. Snow Harris had awakened his special interest in the phenomena of lightning. In his treatise on *The thunderstorm* he sought to promote the general understanding and to reduce the fear of lightning, and to show how to minimize its dangers. There prevailed at the time the widespread belief that burns of a ramified tree-like outline often found on the bodies of animals or men who had been struck by lightning were an image of the tree under which the victim had taken shelter. So fantastic a view, rationalized in terms of a ‘photoelectric’
effect by the French meteorologist Poëy, was indeed hardly tenable. Tomlinson dis-
missed it decisively by showing experimentally, using artificial surfaces, that the
observed patterns were in fact traced by the forked passage of the lightning over the
surface of its target, a demonstration that was favourably received at the British
Association Meeting in Manchester (1861).

Vague notions and errors concerning lightning that persisted in the Press provoked
Tomlinson’s swift correction. He identified alleged ‘novel excentricities’ of lightning as
familiar brush, glow or ball discharges, all obeying the well-established laws of electro-
statics. His comments on the direction of lightning discharge, on the protection of
buildings, ships and powder-magazines, and on the controversy between the advocates of
sharp-ended or blunt-ended lightning conductors settled many uncertainties. In an elab-
orate dissertation on the theory of hail he adduced evidence in favour of the cyclonic
theory accounting for the peculiar multi-layered structure of large hailstones.

Not surprisingly, Tomlinson’s attention was aroused by the claims made for the use-
fulness in weather forecasting of the so-called ‘storm-glass’, which had received the sup-
port of meteorologists including the influential Admiral Fitzroy. The simple device
consisted of a closed cylindrical phial, partly filled with a suspension of potassium nitrate
and ammonium chloride crystals in an aqueous-alcoholic solution of camphor. The crys-
tals were said to accumulate on the bottom of the liquid in fine weather, but tended to rise
in rainy and especially stormy conditions. Tomlinson showed that the movement of the
solid phase was nothing but its usual preferential deposition at the coldest part of the ves-
sel, and that any meteorological claims were spurious.

In another context, Tomlinson reviewed in depth the phenomena of dew formation.
Dr W. Wells FRS had shown that dew is deposited in clear calm nights by condensa-
tion of the water vapour of the air close to surfaces that are themselves chilled by heat
radiation to the sky. His celebrated Essay on dew earned him the Rumford Medal of The
Royal Society. Although Tomlinson respected Wells’s contribution, he concluded that
Wells’s crucial experiments had been anticipated by several investigators (including C.
LeRoy, M. A. Pictet, P. Prevost and particularly P. Wilson of Glasgow), who had actu-
ally foreshadowed his interpretations in brief but unmistakable terms. Tomlinson’s ver-
dict that Wells had unjustifiably ‘written in the style of a man who is announcing original
discoveries’ was, for once, unduly severe, because Wells had indeed referred to Wilson’s
and Prevost’s previous work and had displayed great ingenuity in marshalling the iso-
lated facts into a coherent hypothesis, which has in its main features stood the test of
time. When in later years Aitken revised the prevailing views on the strength of his
fresh experimental data, Tomlinson became embroiled in a controversy, in which on
balance his opponent prevailed.

Tomlinson’s delight in combining science and literature motivated him to compile,
from the letters of the poet William Cowper, a record of the severe winters between 1781
and 1784, when frost continued for nine weeks in Buckinghamshire and froze the ink in
the poet’s inkwell.
While still a young teacher in a provincial town remote from library and laboratory, Tomlinson had already begun modest original scientific work of his own. His first venture was a study of the modes of vibration of sounding bodies, such as ‘musical glasses’. He systematically traced their nodal points and lines by the surface patterns assumed by liquids, especially mercury, contained in the vibrating glass, and correlated the emitted notes with the size, shape and material of the resonators, and the depth of liquid contained in them.45

A chance observation made during these experiments led to an optical discovery: with the object of reducing the turbulence of the vibration figures, Tomlinson covered the mercury in a musical glass with a shallow aqueous layer (which happened to be red litmus solution). When viewed obliquely, the two liquid surfaces produced two separated reflections of the inner rim of the vessel, namely an upper red image reflected by the red aqueous layer, and a lower image reflected by the mercury surface in the complementary (light green) colour. Other pairs of complementary colours were similarly generated. By replacing the mercury surface with a plane mirror, and the coloured solution with a thin glass lozenge of a chosen tint, Tomlinson constructed a simple contrivance (his ‘perichromoscope’) which reflected two images of an object simultaneously in its principal and complementary colour.46 This invalidated all theories that sought to explain the appearance of complementary colours in physiological terms (for example, by the diminished sensibility of the retina of the fatigued eye), but demanded a purely physical interpretation, towards the establishment of which Tomlinson made some sensible suggestions.47

Another early success was his discovery of a new method of producing Newton rings by subjecting a thin film of oil of turpentine spread on water to a descending stream of ether vapour. The lowered surface tension immediately below the ether source resulted in a lateral outward displacement of oil; the thickness of the film was thereby sufficiently reduced for the Newton rings to appear. A few years later the eminent physicist Sir David Brewster, evidently unaware of Tomlinson’s experiment, which had been reported in one of the less well-known journals,48 published similar findings,49 thus implicitly confirming his young predecessor’s work. Experiments involving stroboscopic phenomena and novel optical illusions served chiefly to provide effective demonstrations for Tomlinson’s teaching.50

When after his appointment at King’s College School Tomlinson was able to devote himself more consistently to scientific research, he concerned himself with two main topics, namely liquid surface phenomena and the behaviour of supersaturated solutions. Complex though these projects were, they could be studied with simple apparatus, a fortunate circumstance that enabled him to continue the experiments in his private laboratory at Highgate after his retirement in 1868.

**Cohesion figures**

Tomlinson’s long-standing interest in surface phenomena51 led him to examine the spreading of oils on water and other liquids. He established that the films broke up into patterns (‘cohesion figures’52 that were characteristic of each individual oil or
compound but were radically altered by the smallest amounts of impurities. These phenomena, ascribed by Tomlinson to the interplay of opposing cohesive and adhesive forces, held out hopes of providing a rapid empirical test for detecting the adulteration of essential oils of commerce with inferior substitutes, a problem for which the existing analytical techniques offered no simple solution. The widespread general use of this empirical test was unfortunately frustrated by its very sensitivity and elusiveness. Indeed, three-dimensional cohesion figures, formed by drops of liquids descending through specifically lighter media (for example essential oils in alcohol) were too complex and diverse to admit of any rational interpretation.

In related experiments, Tomlinson investigated the spontaneous circular motion of certain substances on liquid surfaces; the remarkable gyration of camphor on water was the classical example that had long baffled distinguished investigators, including Volta, Prévost, Carradoni, Biot and Sir Humphry Davy. It was suggested that a floating piece of camphor emits continuously a little of its substance as a thin film, which spreads outward on the water. This is simultaneously lost by volatilization and dissolution, and replaced by fresh ‘waves’ of film from the camphor. With its irregular outline, the fragment sends out films in many directions, and is acted upon by corresponding opposite recoil forces resulting in its gyration. The movement continues as long as camphor films are emitted and evaporate, but stops abruptly when a film of a fixed oil (such as olive oil, applied to the surface as a minute drop) displaces the camphor film. The postulated colourless transparent camphor films were invisible, but gyrating benzoic acid flakes emitted visible films, as did solidified oil of aniseed, eugenol and creosote.

In an instructive demonstration supporting this proximate interpretation, Tomlinson supported a stick of camphor of triangular cross-section dipping vertically into water, the surface of which was dusted lightly with lycopodium powder. As a film is emitted from each face of the camphor, the lycopodium is instantly repelled outwards, in the three main directions from the faces of the column; after a pause, during which the film volatilizes and the lycopodium resumes its even spread, the process repeats itself in a series of pulsations that continue for many hours. The action fails when set up in a closed space that prevents the continued vaporization of the camphor.

A more rigorous interpretation of the phenomena was proposed by the Belgian physicist, Van der Mensbrugghe, who identified the surface tension of liquids as the immediate source of the tensile forces that govern the movement of floating particles on liquid surfaces. Tomlinson recognized the merits of this explanation, which introduced a quantifiable vector into the concept of cohesion forces, and reassessed his results in its light. The meeting of the two men on common ground led to their mutual regard and friendship. In after years, Tomlinson referred occasionally to these researches, when commenting on the work of successors in this field.

Supersaturated solutions
From 1868, for a period of some 10 years, Tomlinson devoted much effort to the study of supersaturated solutions of salts, thereby entering another treacherous field, in which conflicting rather than concordant experimental results had dominated its history and have indeed persisted into recent times. Tomlinson chose to reinvestigate the behaviour
of sodium sulphate, the classical but by no means simplest example of the phenomenon (figure 2). It was known that the solubility of the decahydrate (Glauber’s salt) reaches a maximum at 32.5 °C (figure 2, curve AB), but decreases thereafter, being now that of the anhydrous salt (curve BD). The more soluble heptahydrate (curve FE) separates from solution between 34 and 17 °C under controlled conditions; the interrelation between the three forms was not fully understood: according to the prevailing view, supersaturation did not occur in reality but was a consequence of the transformation at 32.5 °C of the dissolved decahydrate into the more soluble heptahydrate.

In contrast, Tomlinson endeavoured to prove that supersaturation was maintained simply by the absence of nuclei that, when introduced, initiate the separation of the solute by the exertion of adhesive forces. The extensive and painstaking although simple experimental work that he undertook to this end can here be summarized only briefly (but is substantiated by complete references).

He confirmed that supersaturated sodium sulphate solutions, prepared under strictly ‘clean’ conditions (that is, with the exclusion of all potential crystallization nuclei) when exposed to an ordinary town atmosphere, precipitated crystals more or less immediately. In the pure air of the country no such separation occurred for many hours or days. Similarly, contact of the supersaturated solution with a glass rod, thermometer or spatula resulted in rapid crystallization, but when such instruments were previously ‘cleansed’ with strong acid or alkali, or drawn through a flame, no such effect was produced.

Tomlinson evoked the operation of adhesive forces as the ultimate cause of this behaviour. He suggested that dust, or the surface of instruments that had not been specially cleansed, were contaminated with traces of films of greasy or oily matter, between which and the supersaturated solution the adhesive forces came into play: ‘As there is stronger adhesion between the salt and the oil phase than between the salt and its aqueous solvent, and almost none between oil and water, salt will be attracted to the oily phase’, forming salt nuclei on which crystallization can commence. He presented his findings to the British Association (1868) and again to the academic establishment at the Chemical
Society. In the ensuing discussion the leading chemists of the day (Frankland, Williamson, Odling, Foster, Miller, Vernon Harcourt), while expressing certain reservations, acknowledged the uncertainties in this difficult field; their cautious positive response no doubt spurred Tomlinson to renewed efforts.

To support the adhesion hypothesis, it was clearly desirable to demonstrate the crystallizing influence of oils, not as the postulated invisible films but as integral substances. Tomlinson established that oils (such as olive, sperm, linseed, castor oil and turpentine) did indeed induce the expected crystallization, provided that their surface tensions were low enough to ensure their spread as thin films. The same hypothesis served him to account for the phenomena of ebullition, the release of vapour from boiling liquids and the release of dissolved gases from their solutions. The behaviour of other salts (for example magnesium sulphate or alums) was equally consistent; a few seemingly anomalous observations made with zinc magnesium sulphate and zinc sodium sulphate soon found their rational explanation.

Tomlinson’s essentially qualitative experiments, involving delicately balanced metastable systems, required great care and attention for their successful reproduction. Not surprisingly, other investigators occasionally failed to repeat his results and were inclined to question his interpretations. Tomlinson welcomed such critics ‘not as opponents but as co-adjutors in the pursuit of truth’. When J. G. Grenfell produced a dissenting paper, it was Tomlinson who communicated it to The Royal Society. He was indefatigable in tracing the causes of any inconsistencies: thus, he correlated the influence of changing atmospheric conditions with the appearance of ozone in the air. When the old assertion was revived that crystallization could be induced only by solid particles identical or ‘isomeric’ (meaning isosteric) with the particular supersaturated species, and that microscopic sodium sulphate dust floating ubiquitously in the air provided these nuclei, he once again disproved such objections by experiment.

After an interval of several years, Tomlinson reaffirmed his experimental results and reiterated his general conclusions. Any estimate of his contribution must take cognisance of the difficulties and uncertainties—bordering on the capricious—of this chosen subject. J. R. Partington, reviewing the efforts of many distinguished researchers in this field, concluded that ‘in comparison with the time and trouble expended, the results are not very extensive’. He himself derived the first mathematical expression (the supersaturation isochore) governing supersaturation phenomena. Theoretical approaches to the problem (including the concept of ‘molecular clusters’) have recently appeared with increasing frequency, but an authoritative source still alludes to the ‘strange behaviour and properties of supersaturated solutions’. It is against this background that Tomlinson’s patient and painstaking efforts must be judged.

Miscellaneous researches

Tomlinson was occasionally involved in minor projects, particularly when some prevailing misconception required correction. He showed, for example, that the sublimation of volatile substances such as camphor, and the deposition of crystals from solution, was not attracted towards a strong light source, as was widely accepted, but occurred simply at the coldest available surface. In a series of patient experiments he disproved the sup-
posed\(^8\) crystallizing influence of sunlight on liquid honey: he showed that bees did not prevent their stored honey from solidifying—vital for the nurture of their offspring—by the strict exclusion of light from their hives, but by the addition of traces of salt.\(^8\)

A remarkable phenomenon noticed by Tomlinson was the behaviour of a very finely divided powder such as plumbago, suspended in very slowly cooling beeswax: it was gradually deposited as a ‘net’ of regular hexagons, visualized by Tomlinson to be the effect of parallel vertical convection systems operating within the bulk of the liquid.\(^9\) In the context of his lectures he continued to devise novel or improved demonstration experiments, dealing with the ‘electric vane’, consecutive poles of long magnets, and Chladni’s figures.\(^9\) He examined the range and echo of sound, and identified certain noises of mysterious origin resembling the firing of cannon as globular lightning discharges.\(^9\)

In an ingenuous experiment, Tomlinson—now in his 84th year—simulated the formation of ‘rocking stones’ by the process of weathering, in which the upper of two blocks of stone is worn away faster than the base. He accelerated the process by the use of two identical small slabs of camphor, one placed on top of the other, when preferential volatilization reduced the upper more exposed component to precisely the shape, that allowed it to be rocked on the base (figure 3).\(^9\) His occasional encounters with a variety of minor chemical problems always elicited an astute and illuminating response, by experiment or commentary.\(^9\)

**SCIENTIFIC SOCIETIES**

As a lively and gregarious character, Tomlinson derived much satisfaction and pleasure, both professional and social, from his membership of several scientific societies.

**The Cavendish Society**

He was an original subscriber and Council member (along with such eminent colleagues as Thomas Graham, Faraday, Hofmann and Brande) of the Cavendish Society. It had been formed in 1846 with the specific object of promoting the publication of major works on chemistry, especially the translations of foreign texts that, for financial reasons, found no favour with the commercial publishing houses.\(^9\)

One of its first acts was to commission Dr George Wilson\(^9\) to produce a definitive biography of the scientist whose name it bore. Wilson did not confine himself to
Cavendish’s scientific achievements but explored his character and recounted the numerous anecdotes that circulated about the notorious shyness and unworldliness of his subject. For many of these he was in fact indebted to Tomlinson, who made it his business to gather them from the great man’s surviving contemporaries and other sources. Tomlinson went out of his way to interview the occupant of Cavendish’s country villa at Clapham, a Mr Herbert, whose wife was ready to add further touches concerning Cavendish’s retiring ways, especially where the female sex was concerned; Dr Sylvester, a local medical practitioner, confirmed several details. Finally, it was through Tomlinson’s diligence that the only known portrait of Cavendish was found in the print room of the British Museum, together with the whimsical circumstances under which the artist W. Alexander had secretly accomplished his task. Wilson’s stock of anecdotes has been retold time and time again, and Tomlinson’s part in their rescue from oblivion was indeed minutely identified by Wilson himself.

The British Association for the Advancement of Science
Tomlinson was admitted as a life-member of the British Association in 1864, but had already before that date read papers at its annual meetings, at Manchester (1861) and at Cambridge (1862), presumably with the encouragement of Professor Miller, who served on the Chemistry Committee at the time. Thereafter, he regularly enjoyed attending the meetings in the various provincial centres, giving presentations of his researches in Bath (1864), Nottingham (1866), Norwich (1868), Exeter (1869), Liverpool (1870) and Edinburgh (1871). After the death in 1872 of his wife, who had been his constant companion at these meetings, his name disappeared from the list of active participants. However, he continued a member to the end of his life, and served, from 1868 to 1876, on the Association’s special Committee that monitored, recorded and evaluated statistically the rainfall throughout the British Isles.

The Royal Society
Tomlinson was elected a Fellow of The Royal Society in 1867, his candidature being supported by a distinguished list of sponsors. His nomination paper was signed ‘from personal knowledge’by Thomas Graham, President of the Chemical Society, Alexander W. Williamson, Sir Frederick Augustus Abel, E. W. Brayley, W. Snow Harris, Neill Arnott and J. H. Gladstone, while those supporting his candidature ‘from general knowledge’ were headed by Faraday and E. Frankland.

Tomlinson published his most important papers in the Philosophical Transactions or in the Proceedings of the Society. A quarter of a century previously, he had written a brief account of its history, especially of the period of Sir Joseph Banks’s presidency. He now served on the Library Committee, and on one occasion rallied to its defence in the matter of a dispute involving A. Panizzi that had occurred many years before but was resurrected in the biography that appeared shortly after Panizzi’s death. While still in a subordinate position at the British Museum, Panizzi had been engaged by The Royal Society to compile a new catalogue of its Library. Difficulties arose at once, when he rejected any interference, insisting, for example, on adding personal comments to some of the catalogue entries. When the Library Committee objected to being party to opinions
that they did not share, Panizzi was outraged, and aired his grievances in two bitter pamphlets. The strained relations between the parties ended with the termination of Panizzi’s commission in 1837. When his biographer recounted this incident entirely from Panizzi’s point of view, Tomlinson felt in duty bound to present the Society’s case, which he did with good humour, although not without faint sarcasm.\textsuperscript{106}

Tomlinson’s extensive bibliographical expertise was enlisted when the removal of obsolete books from the Society’s library had to be addressed. Together with Sir John Evans, Treasurer, he separated the historically important from the merely antiquated, and provided guidance for the pruning of the library’s holdings accordingly.

The repeated assertion that Tomlinson was a founder-member of the Physical Society of London could not be substantiated. The claim might have arisen from an entry in the Society’s Minutes recording the election on 20 June 1874 (the foundation year) of ‘H. Tomlinson, BA’.\textsuperscript{107} Tomlinson’s membership of the Chemical Society, dating from 1864, must have lapsed before his death, because no obituary appeared in the Society’s Journal.\textsuperscript{108}

\textbf{The Highgate Literary and Scientific Institution}

On his arrival in Highgate in the spring of 1866, Tomlinson was immediately involved in the activities of the local Literary and Scientific Institution, which had been formed (in 1839) in the ardour of the Institution movement of the early nineteenth century. This society offered its members the usual facilities of a library, meeting and reading rooms and, most importantly, a hall where lectures were regularly delivered (figure 4).\textsuperscript{108} Tomlinson served the Institution enthusiastically and devotedly for nearly 30 years. As its Secretary (1867–76), President (1876–77), and subsequently as its Treasurer, his presence made itself felt in both the academic and administrative spheres. Most significantly, he raised the then relatively low profile of the sciences by encouraging an increase in the proportion of scientific and technical lectures, in which a general audience could take an

\begin{figure}[h]
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\caption{The home of the Highgate Literary and Scientific Institution, occupied uninterruptedly since 1839.\textsuperscript{108}}
\end{figure}
intelligent interest. This he was able to do by attracting prominent scientists of his own acquaintance, including James Tennant FGS, W. A. Miller FRS, C. V. Boys FRS, W. Huggins FRS and others. Tomlinson himself lectured regularly every Season on a variety of scientific subjects, skilfully blending instruction with ‘rational entertainment’. His talks on ‘Science connected with a tea-kettle’ recall Faraday’s famous lectures on ‘The chemistry of a candle’. At other times he dealt with miscellaneous chemical topics, the lives of famous scientists, or subjects related to his own research interests. His regular courses on chemistry and natural philosophy held at the Institution were popular among pupils of local private schools that were unable to provide such tuition.

The Game of Chess

It was characteristic of Tomlinson that he enjoyed exerting his mental powers even in his recreation, in his devotion to the game of chess. He acquired great competence, and as usual laid down his knowledge and experience in print. His manual entitled Amusements in chess was in fact a scholarly work that was long considered the best elementary introduction to the game. He also published a collection of Chess poems prefaced with his reminiscences of Simpson’s ‘chess divan’ in the Strand in the 1820s, as well as an Ode celebrating in 900 heroic couplets all aspects of the game. It included a move-by-move description of a chess contest in the style reminiscent of the game of cards in Pope’s Rape of the lock. At Highgate, Tomlinson’s passion for chess continued undiminished: he was said ‘to enter upon a game with eager seriousness … and generally march to victory with the inevitableness of Fate’.

The Man of Letters

Tomlinson’s keen interest and talents in the humanities found expression in his sensitive translation of foreign poetic works, in the composition of his own poems, and his contributions to literary criticism. In the present context only the briefest reference to these activities can be made, important though they were in his intellectual life.

Hermann and Dorothea

Tomlinson’s thorough knowledge of the German language gave him the confidence to translate Goethe’s epic poem ‘Hermann and Dorothea’ in its original metric form of the classical hexameter. As one of the best-loved of Goethe’s creations, it was translated into the principal European languages, appearing in no less than 20 English versions, in both prose and rhyme, one being the anonymous effort of another scientist, W. Whewell. Tomlinson’s feat of producing his translation in the form of some 2000 hexameters, keeping closely to the original, earned him the approbation and praise of the leading contemporary German Goethe scholars and critics.
The sonnet

Tomlinson’s first love in literature, however, was the Italian sonnet, as perfected by Petrarch and Dante. His scientific mind was instinctively attracted by the perfection of its succinct structure of 14 lines, conforming with almost mathematical precision to strict rules, both as to its metrical form and the logical development of its theme. In his scholarly treatise on the subject he classified, according to their metrical pattern, all 341 sonnets of Petrarch, as well as numerous examples of Dante (40), Michael Angelo (80), Tasso (223), and others. He analysed the contents and merits of many examples, and appended his own English translations, reproducing as far as possible the poets’ simple and eloquent language in the original metre. The collection of 59 sonnets in the Petrarchian mould from his own pen is noteworthy for his choice of numerous scientific themes, a unique performance that dealt with the nature, purpose and power of science itself, and celebrated the memory of great scientists such as Priestley and Faraday.

Dante studies

Tomlinson’s most ambitious project was the translation of Dante’s *Inferno*. According to his self-imposed exacting guidelines, a faithful translation had to combine close literalness, adherence to the original metric form, and the true preservation of the spirit of the model. Accordingly, Tomlinson adopted a plain line-for-line rendering, adhering to Dante’s metrical form of the tierce rhyme (*terza rima*), even though its use was less adaptable to the English than the Italian idiom. His deliberate aim of producing the most accurate possible translation was no doubt influenced by his ingrained scientific attitude that valued precision and veracity above the luxury of poetic licence, and resulted in a sober rather than inspired production. At a chance meeting, Robert Browning expressed his amazement to Tomlinson at his rendering the whole of the *Inferno*, comprising some 5000 lines, in English tercines, and congratulated him on this feat; he, himself, however ‘demanded in a translation the spirit of a man, not the letter’. Indeed, not everyone shared Tomlinson’s insistence on the use of tercines: in the opinion of Rossetti, blank verse was the best medium for translating Dante into English.

The Barlow Lectureship

Contemporary opinion of Tomlinson’s merits as a scholar of Italian Renaissance poetry was high, and secured his appointment as the first Barlow Lecturer at University College London. Dr D. C. Barlow, an eminent Dante student, had endowed the Lectureship with the object of providing an annual course of 12 public discourses on *The divine comedy*, to be delivered by a lecturer appointed for a term of three years, evidently to encourage a consistent coverage of the three great divisions of the poem. In the spring of 1878 Tomlinson delivered his course on *Inferno* to a large and appreciative audience, and completed the cycle in the following two years; it gained him the friendship of Christina Rossetti, who attended the courses regularly. He subsequently incorporated some of the material of these lectures in his last book, in which he examined critically Beatrice’s role in *Dante’s Vision* and life.
PERSONAL NOTES

Family and social life

Tomlinson married in Salisbury in 1839 Sarah Windsor, the younger sister of Maria, who had become the wife of his elder brother, Lewis, four years previously. The Tomlinsons’ first London home, at 12 Bedford Place, Euston, was exchanged on his appointment at King’s College for a larger house at 178 Hampstead Road, where they received occasional out-of-town college students as boarders. Mrs Tomlinson was a favourite hostess whose popular Saturday evening parties were attended by young scientists, writers and artists. Professor DeMorgan,125 the eminent mathematician of University College London, who lived nearby, was a frequent guest, as was the authoress Mrs Oliphant;126 she was the only one who was welcomed with some uneasiness, lest some of the other visitors find themselves portrayed in her next novel.

On their arrival at 7 North Road, Highgate, in 1866, the Tomlinsons were quickly accepted into a community remarkable for its social cohesion and decided intellectual aspirations. Tomlinson’s services were promptly recruited by the Highgate Literary and Scientific Institution, that would henceforth be one of the central interests of his life. After only six very happy years in these congenial surroundings his wife died (1872). It was not until 1881 that his niece, Mary, who had lost both parents in quick succession, joined him in London, and proved a faithful helpmeet in his declining years.

Personality and character

Tomlinson had, by common consent, an attractive and generous personality, which gained him the goodwill and sympathy of all who met him. Of a gregarious disposition, he enjoyed the companionship of a large acquaintance, and the intimacy of several close friends. His lively conversation, always informed but never overbearing, no less than his tact as a good listener, made him an agreeable companion at any gathering. His accurate memory covered the age from the reign of George IV and William IV (when the streets of London were lit with oil lamps) to the 60th anniversary of Queen Victoria’s accession. He had experienced the profound changes that had occurred in the wake of the Industrial Revolution, and the resulting social and technical upheavals, and was ever ready to give enthralling personal accounts of what he had witnessed.

A consistent picture of Tomlinson’s character emerges from the evidence of his own writings and activities, and the testimony of friends who knew him best.127 His incisive prefaces, commentaries and, above all, his essays128 reveal him as a man who combined intellectual integrity and liberal opinions with sound common sense, who set himself and others high standards, and pursued a lifestyle that was fulfilling to himself and useful to others, in preference to the mere pursuit of material and outward rewards. He never concealed his humble origin, but referred cheerfully to his early struggles, taking comfort in having risen above them by his own exertions. He was nevertheless acutely aware of the disadvantages that the lack of a good schooling and university education entailed, for the acquisition of a balanced and liberal stock of knowledge no less than for the development of self-confidence, open manners and urbanity, so important in social and professional intercourse.129
Tomlinson was a man of profound religious feelings that centred ultimately on celebrating the wisdom and goodness of the Creator. His early strict adherence to the doctrines of the established church was sustained, on the one hand, by his and his brother’s dependence on the goodwill of the Bishop of Salisbury, but perhaps even more persuasively, on the other, by the unwillingness of Charles’s prospective father-in-law to bestow his daughters on anyone suspected of the slightest deviation from orthodoxy. In his later years he focused increasingly on moral rather than doctrinal aspects and would probably have described himself as a broad churchman with Unitarian leanings.

In his person, Tomlinson was described as having the air of the scholar that expressed intellectual power and alertness, as well as kindliness, and reserves of wit and humour. His portrait, apparently the only surviving one, has been preserved at the Highgate Literary and Scientific Institution (figure 4). He was fortunate in enjoying good health into his old age, and his full mental powers to the end. Even the deterioration in middle life, and the eventual loss of the sight of one eye, was not allowed to interfere seriously with his work until the very last years of his long life. Tomlinson died on 15 February 1897 and was buried, as was his wife before him, in Highgate Cemetery.

The repeated statement that Tomlinson ‘gave up science for poetry’in his later years is clearly simplistic. His predilection for literature had its roots even in his pre-Salisbury years and continued while he was fully engrossed in his professional scientific work. Conversely, his scientific activities did not cease after his retirement from King’s College but proceeded uninterruptedly in the modest laboratory that he had installed in his Highgate house. Indeed, of his 107 published papers and notes, about two-thirds (68 items) appeared from the year 1867 onwards, including much supplementary experimental work on supersaturation. Tomlinson liked to look on science and literature as the ‘twin-sisters of learning’, and he confessed himself to be in love with them both. It is only natural that literary studies, which in his prime had been a favourite relaxation, became the solace of his old age.

**CONCLUSION**

Charles Tomlinson’s life was spent in the service of science and technology, and in the pursuit of knowledge for its own sake. In spite of unpromising beginnings, he rose in his profession by his innate talents, largely as an independent practitioner in an age when the institutionalization of science was all but complete and when the pursuit of a successful scientific career was difficult and uncertain without the support of an academic, official or industrial position.

Tomlinson deservedly enjoyed a high reputation among his contemporaries, and his achievements are no less admirable when viewed a century and a half after they were accomplished. His prolific writings contributed substantially to the dissemination and stimulation of technical knowledge in his time. His researches in the uncharted borderland between physics and chemistry were pursued with patience and perseverance, and their value, especially in the field of supersaturation, was recognized by so eminent an authority as Clerk Maxwell. Tomlinson’s diligent and significant contributions to the cause of science entitle him to an assured place in the annals of intellectual progress.
ACKNOWLEDGEMENTS

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NOTES

2 [E. Irving Carlyle], Dictionary of national biography [hereafter DNB], vol. 19, pp. 945–946 (1917).
3 [Obituary], Nature 55, 371 (1897); The Times, 16 February 1897; Br. Chess Mag. 17, 109–114 (1897); Notes and Queries 11 [VIII], 160. See also note 114.
7 John William Parker (1792–1870) established his publishing house at 445 Strand, in 1832 and was appointed Publisher to the Society for the Promotion of Christian Knowledge, and Printer to the University of Cambridge in 1836. He published the works of such eminent authors as John Stuart Mill, Buckle, Whewell, Kingsley and Froude, and issued major textbooks, several written by his neighbours, the professors of King’s College. DNB 15, 251–252 (1917).
8 William Snow Harris (1791–1867; FRS 1831), physicist and engineer; DNB 9, 30–31 (1917).
9 J. F. Daniell, Elements of meteorology (John W. Parker, London, 1848), i.e. 3rd edn of Meteorological essays and observations (T. & G. Underwood, London, 1823–27).
11 W. A. Miller, Elements of chemistry (London 1855–57); 6th (last) edn revised by H. E. Armstrong and C. E. Groves (John W. Parker, London, 1880).
12 [King’s College], Report from the Council to the Annual General Court of Governors and Proprietors 1858 (London, 1858).
13 [C. Tomlinson], Inaugural Lecture held at ... the Birkbeck Literary and Scientific Institution, 1883 (for the author, London, 1883).
15 Virtue & Co. were the proprietors of the Art Journal and publishers of illustrated topographical and art books of unsurpassed quality and beauty, which incorporated the work of the first artists and engravers of the age. They were reputed to have issued over 20000 copper and steel engravings during their business career. DNB 20, 384–385 (1917); Art J., May 1892.
16 The parts, consisting of 48 (and later 36) pages and the appropriate engraved plate, were issued.
They included Joseph Wilson Lowry (1803–79) FRGS, notable for his mastery of technical subjects. DNB 32, 212–213 (1917). James Basire (1796–1869) represented the fourth generation of an unbroken line of engravers extending over 150 years. DNB 1, 1278–1280 (1917).

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18 See also C. Tomlinson, On the invention of printing (privately printed, London 1865).

19 The article appeared subsequently in book form under a different imprint, but with the original illustrations: G. F. Ansell, The Royal Mint: Its working, conduct and operation ... with suggestions for its better scientific and official management (Effingham Wilson, London, 1870).

20 Encyclopaedia Britannica or Dictionary of arts, science and general literature, 8th edn (Adam & Charles Black, Edinburgh, 1853–60). Tomlinson was listed among the principal authors, in the company of such leading scientists as Brewster, Herschel and Playfair. His were chiefly industrial topics, including gas-lighting, pottery, sugar and tobacco.


22 The copyright of these volumes, forming Weale’s Rudimentary Series, was acquired by Virtue & Co, who continued to reprint them. The following list quotes their number in the series (when known) and the year of publication of an accessible edition: Rudimentary mechanics (London, 1849; later edns 1851, 1867) (no. 6); A rudimentary treatise on warming and ventilation (London, 1850; later edn 1858); Pneumatics for the use of beginners (London, 1848), reissued as Pneumatics, including accoustics and the phenomena of wind currents (London, 1887) (no. 12); Experimental essays (London, 1863) (no. 14).

23 Introduction to the study of natural philosophy (London, 1848); The natural history of common salt (London, 1855–64); Illustrations of the useful arts and manufacturers (London, 1859); Objects in art and manufacture (Board of Trade, London, 1854); History of printing (SPCK, London, 1855, 1862); Illustrations of trades (SPCK, London, 1860); The magnifying glass (London, 1867); Experiments on a lump of camphor (Virtue & Co., London, 1876).

24 Tomlinson, Natural philosophy (note 23).


26 Tomlinson, item ii (note 10).


30 C. Tomlinson, ‘Are thunderstorms more frequent in towns than in the open country?!’, Symons’s Meteorol. Mag. 23, 121–122 (1888), and op. cit. (note 29).


32 Robert Fitzroy (1805–65; FRS 1851), Vice-Admiral, meteorologist, commander of HMS Beagle during Darwin’s voyages (1831–36); DNB 7, 207–209 (1817).


34 Tomlinson, item iv (note 10), chs II–V.


36 W. C. Wells, An essay on dew and several appearances connected with it (Taylor & Hessey, London, 1814).

39 Patrick Wilson (1758–?1811), professor of Astronomy at Glasgow University; *DNB* 21, 545–546 (1917).

40 P. Wilson, ‘Experiments and observations upon a remarkable cold’, *Trans. R. Soc. Edinb.* 1 (ii), 117–119 (1883) (communicated by Dr Black, 5 July 1784).


51 C. Tomlinson, ‘On the action of certain vapours on films, on the motion of creosote on the surface of water, and other phenomena’, *Phil. Mag.* 22, 111–120 (1861) (a letter to Dr Miller); *Br. Assoc. Rep.* 31, 93 (1861).


56 C. Tomlinson, ‘On the motion of camphor on the surface of water’, *Phil. Mag.* 24, 490–491 (1862); see also *Experimental essays* (note 22), ch. 1.


59 C. Tomlinson, ‘On the motion of eugenic acid on the surface of water’, *Phil. Mag.* 27, 528–537 (1864); ‘On some physical properties of eugenic acid’, *Chem. News* 10, 63–64 (1864); ‘On some phenomena connected with the adhesion of liquids to liquids’, *Phil. Mag.* 33, 401–412 (1867).


61 G. van der Mensbrugghe, ‘Sur la tension superficielle des liquides considérée au point de vue de
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certains mouvements à leur surface’, Mémoires Couronnés (et autres) de l’Académie Royale des Sciences etc de Bruxelles [1869]. 34 (1870); 37, no. 4 (1873).


For discussion, see C. Tomlinson, ‘On the constitution of sodic sulphate in solution, Phil. Mag. 37, 267–268; 277–279 (1869).


72 C. Tomlinson, ‘On the action of solid nuclei in liberating vapour from boiling liquids’, Proc. R. Soc. Lond. 17, 240–252 (1869); 37, 113–114 (1884); Phil. Mag. 49, 432–448 (1875); 50, 85–100 (1875); ‘On bumping ebullition (soubresante)’, Chem. News 57, 244; 58, 235 (1888).


See, for example, D. J. B. Gernez, ‘Sur la cristallisation des dissolutions salines sursaturées et sur la présence normale du sulfate de soude dans l’air’, Comptes Rendus 60, 833–837, 1027–1030 (1865), and subsequent papers.

Frederick Kurzer


99 William Alexander (1767–1816), artist and keeper of prints and drawings in the British Museum; *DNB* 1, 281 (1917).

100 Wilson, *op. cit.* (note 97), preface: ‘I have reserved for special thanks Charles Tomlinson, Esq. of London, to whose untiring zeal, skilful investigation and cordial unflagging co-operation I am
indebted to the larger part of the materials, from which the … concluding events of Cavendish’s life, and estimate of his moral and intellectual character … have been compiled. He has also done me the favour to read the proofs of this work, besides assisting me in every other way in which he could be of service.’

101 The statement that Tomlinson was elected to the Council of the British Association (notes 2 and 3) has not been confirmed and seems to be erroneous.


103 Antonio (later Sir Anthony) Panizzi (1797–1879), Italian patriot, Assistant (1831), Keeper (1837) and Principal Librarian (1856–66) at the British Museum, creator of its Library Catalogue, and its famous domed Reading Room. He had small love for the sciences and its professors, and according to his friend Macaulay ‘would at any time give three mammoths for one Aldus’. DNB 15, 179–183 (1917).


105 Panizzi’s remuneration was agreed at £30 per thousand titles, with an upper limit of £500.


107 This may have been Charles Henry Tomlinson (C.T.’s nephew), who graduated BA(Oxon) in mathematics and natural philosophy in 1857, and became Vicar of Denchworth, near Wantage (1868).


109 Paraffins and paraffin oils (1871), Manufacture of iron (1874), Chlorine and iodine (1883), Faraday (1887), Franklin (1888), Sir Joseph Banks (1891), Joseph Smeaton, the engineer of lighthouse fame (1890), Solution (1872), Fermentation (1876), Surface phenomena (1885).


114 [Obituary], Br. Chess Mag. 17, 109–114 (1897). This was essentially a reprint of the article in the Biograph and Review (note 1), with added material pertaining specifically to chess.

115 C. Tomlinson, Herman and Dorothea. Translated into English hexameters from the German hexameters of Goethe. With an introductory essay historical and critical (David Nutt, London 1849; 2nd edn revised, 1887).


117 These were J. Karl Rosenkranz (1805–79), philologist (Encyclopaedia Britannica, 11th edn, vol. 23, p. 735 (1911)), and the distinguished philologist and orientalist Friedrich Max Müller (1813–1900), DNB Suppl. III, 151–157 (1901).


119 C. Tomlinson, Sonnets (London, 1881). This small octavo was printed privately for the author for distribution to his friends.


121 Tierce rhyme (terza rima) is a continuous sequence of three-line verses (tercets), in which the rhymes interpenetrates one another according to the scheme  

ABA , BCB , CDC , DED …,

which powerfully moves the flow of action forward. It requires three rhymed endings for each consecutive pairs of tercets, less readily available in English than in Italian.
Henry Clark Barlow (1806–76) MD, scholar and writer on Dante. The lectureship bearing his name was endowed by his bequest of £1500. *DNB* 1, 1141–1142 (1917).


Augustus DeMorgan (1806–71), first president of the Mathematical Society (1868); *DNB* 5, 781–784 (1917).

Margaret Oliphant (1828–97), novelist and historical writer. She settled in 1852 in Harrington Square, near the Tomlinsons’ house in Hampstead Road; *DNB Suppl.*, 1102–1106 (1917).

See Tomlinson, *op. cit.* (note 4), especially ch. XIV.


See biographies (notes 1 and 3).


Tomlinson, *op. cit.* (note 4), p. 80, as reported by Professor W. A. Miller.