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Stokes's Mathematical Education

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Keywords: Stokes, Bristol College, Cambridge Mathematical Tripos

Summary

George Gabriel Stokes won the coveted title of Senior Wrangler in 1841, a year in which the examination papers for the Cambridge Mathematical Tripos were notoriously difficult. Coming top in the Mathematical Tripos was a notable achievement but for Stokes it was a prize hard won after several years of preparation, and not only years spent at Cambridge. When Stokes arrived at Pembroke College, he had spent the previous two years at Bristol College, a school which prided itself on its success in preparing students for Oxford and Cambridge. This article follows Stokes's path to the senior wranglership, tracing his mathematical journey from his arrival in Bristol to the end of his final year of undergraduate study at Cambridge.

Introduction

By the time Stokes set off for Bristol College in 1835, his aptitude for mathematics was already in evidence. At an early age he had been tutored by the local parish clerk in Skreen in Ireland who taught him mathematics using Voster's *Arithmetic*, a popular text "adapted to the Commerce of

Ireland” [1].¹ The clerk had been delighted by the fact that the young Stokes had quickly worked out “new ways of doing sums” far better than those given by Voster [2 p5]. In 1832, aged 13, he was sent to Dublin where he lived with his uncle, John Stokes, and attended the famous school of Dr Wall. Here again he was noticed for his facility with mathematics, although this time it was his ability to solve geometrical problems that attracted attention.

In 1834 when Stokes’s father, the Rector of Skreen, died and the family had to give up the Rectory, the decision was made to send Stokes to school in England. Bristol College was chosen on the recommendation of Stokes’s brother, William Haughton, who had studied in both Dublin and Cambridge with the principal of the College, Joseph Henry Jerrard.²

Bristol College

Bristol College had been founded in 1830 as the first institution of higher education in Bristol. From the outset, mathematics was deemed an essential area of study— something that was not the case in all schools at the time, Eton and Harrow providing conspicuous examples—as it was part of a liberal education, the notion so strongly advocated by William Whewell.³ The course of study of mathematics at Trinity College, Cambridge, provided the model, as detailed in the prospectus [6 p6, 9-10]:

¹ Further details of Stokes’s early life and education can be found in the ‘Notes and Recollections’ by Stokes’s daughter, Isabella Humphry, [2 p3-5], and in [3] from which this article is adapted.

² The name Jerrard is familiar to historians of mathematics through Joseph Henry’s brother, George Birch Jerrard. The latter was well-known in his day for his publications on the theory of equations, and, in particular, for his mistaken belief that he had found a formula for solving equations of the fifth degree, a belief he continued to hold long after the publication in 1826 of Abel’s proof that the general equation of fifth degree cannot be solved by radicals.

³ Whewell originally set out his ideas in ‘Thoughts on the study of mathematics as a part of a liberal education’ in [4 p143-181] to which he added further remarks in the second edition published in 1838. For a discussion of Whewell’s influence on Cambridge mathematics, see [5].

Experience has proved, that a close application to the exact sciences is the best discipline for the mind, and the most suitable preparation for its advancement in the schools of philosophy. The Mathematics are therefore justly held to be an essential part of every liberal education. . . . The Mathematics will be taught in separate classes. . . . It is intended however to adopt, with no more alteration than can be avoided, the plan at present pursued in Trinity College, Cambridge. It is expected, that the student will have been grounded in the elements of Geometry and Algebra, while in the junior classes. He will then proceed to Plane Trigonometry, to the higher parts of Algebra, and having become acquainted with the Differential and Integral Calculus, to the theory of Curves, and successively to Statics and Dynamics, Conic Sections, and the first three sections of Newton's *Principia*. Thus far he may advance in the first and second years : in the third, he will be occupied with the principles of Hydrostatics and Optics, and with the remainder of the first book of the *Principia*, as well as with Spherical Trigonometry and Physical Astronomy.

When Bristol College opened its doors on 17 January 1831 it had about thirty pupils, considerably fewer than originally envisaged. Owing to the constitution of the College with respect to religion—theological instruction was voluntary—the Bishop of Bristol had been openly hostile to the plan, which meant that the founders had been unable to raise as much capital as they had hoped. Locally, feelings had run high with comparisons being made with “that moral pest-house—the London University” [7 p3]. Despite the opposition, the College quickly achieved success with many of its pupils later attesting to its value. Nevertheless, the College was short-lived. In 1840 a rival school, supported by the local bishop, opened and Bristol College, unable to withstand the competition, closed its doors in 1841.

By the time Stokes entered the school in 1835, two members of staff were high-ranking wranglers, both well placed to implement the course of Cambridge-style mathematics, with one of them, Frederick Will Hill Jerrard, the youngest brother of the principal, having left Cambridge only two years before. There is no record of how Stokes fared under their instruction but one teacher at the College whom Stokes did recall was the writer Francis Newman, younger brother of John Henry

(later Cardinal) Newman,⁴ and “a man of charming character” [2 p6]. Newman had distinguished himself at Oxford gaining a double first in classics and mathematics in 1826 and had joined the College in 1834 as classical tutor. However, it was his mathematics that made its mark with Stokes, and Stokes ‘subsequently corresponded with him on mathematical subjects when both had become famous’ [2 p6]. Although today Francis Newman is remembered as a social and religious reformer, his first publication was a pamphlet on Taylor series, and he went on to write several books and articles on mathematics.

Stokes’s ability for mathematics was readily apparent to those around him at the College and at the end of his first year he was awarded a ‘Grand Prize’ which included a prize in mathematics and a certificate of honour in English prose composition [8 p3]. At the end of his second and final year, he was examined in elementary dynamics, mechanics, the differential and integral calculus, and trigonometry, with oral testing on the last three. He did not win the first mathematics prize but was awarded a prize for “Extraordinary Progress in Mathematics” [9 p4], which suggests that when he arrived at the College he was not as well prepared in mathematics as some of his fellow students.

His final examinations over, the question now was where should Stokes go to next. His father and all three brothers had studied at Trinity College Dublin (TCD), but they had not been to a school which explicitly prepared students for Oxford or Cambridge. Stokes’s brother William had entered TCD at the age of 17 before going up to Cambridge five years later, graduating as Sixteenth Wrangler in 1828. Such a pattern of study was not unusual. The level of mathematics taught at TCD and universities such as Edinburgh, Glasgow, or University College London, was much lower than at Cambridge, and their mathematics courses were considered good preparation for Cambridge. In effect, the mathematics courses at these universities were comparable to the one given at Bristol College.

Joseph Jerrard told Stokes that he had advised his brother William to enter him for Trinity College Cambridge. But when Stokes went up to Cambridge, he did not go to Trinity but to Pembroke. According to Richard Glazebrook, a former student of Trinity, writing in 1901: “A college tradition states that he [Stokes] wished to join Trinity but that the tutors’ lists were full, and the Master [Christopher Wordsworth] declined to sanction the admission of even one more than the

⁴ Newman was canonised on 13 October 2019.

usual number of undergraduates.” [10 p312].⁵ While this may have been true, it is probable that the intensely religious Wordsworth would have been averse to accepting at Trinity, where (on his insistence) chapel attendance was compulsory, any student from the secularly inclined Bristol College, whether the tutors’ lists were full or not. Certainly, no other Cambridge-bound students from Bristol College went up to Trinity.

In 1901, when Stokes recalled his student days, he wrote: “I entered Pembroke College, Cambridge in 1837. In those days boys coming to the University had not in general read so far in mathematics as is the custom at present; and I had not begun the differential calculus when I entered the College, and had only recently read analytical sections.” [2 p7]. It appears, however, that Stokes’s memory was playing tricks on him since, as noted above, the subjects in his final examination at Bristol College included both the differential and the integral calculus.

Cambridge

At the beginning of the nineteenth century, the normal route to a Bachelor of Arts degree at Cambridge was through the Senate-House Examination, popularly known as the Tripos. The examination was primarily in mathematics but included other subjects, such as logic, philosophy and theology. It began to be referred to as the Mathematical Tripos only in 1824, when the Classical Tripos was examined for the first time, although students could enter the Classical Tripos only if they had already obtained honours in the Mathematical Tripos—a situation which pertained until 1850. As the century progressed the examination took on an ever-increasing significance. There was a shift from oral to written examinations, with success in the final examination being paramount, and a concomitant rise in private tutoring without which such success was virtually impossible. A high place in the order of merit garnered national recognition and was a passport to the career of the graduate’s choice.

⁵ At the time of writing his essay on Stokes, Richard Glazebrook was Director of the National Physical Laboratory.
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Mathematics was the core of study at Cambridge not because it was preparation for a career as a mathematician but because it provided a fundamental part of a liberal education. The reason for studying Euclid's *Elements* was not simply to learn geometry. It was a training of the mind. That said, knowledge of Euclid provided (at least some) access to the single most important text a Cambridge mathematics student had to study: Isaac Newton's notoriously difficult *Principia*. Written primarily in the language of geometry, the *Principia* provided the most certain demonstration of human knowledge of the natural world.

Tuition

Undergraduates generally began their studies under the direction of a college lecturer whose duties were to guide the reading of the students and to prepare them for the rigours of the college and Senate-House examinations. When Stokes arrived at Pembroke, the college mathematical lecturer was John Mills (Fifth Wrangler in 1831), so it would have been Mills who acted as Stokes's first point of call. Little is known about the nature of Stokes's studies in his first year except that he came second in the college examinations, pipped by a certain John Sykes. Sykes's family were resident in Cambridge so perhaps Sykes had been better prepared in Cambridge-style mathematics than Stokes. The following year Stokes came out top with Sykes coming only third.⁶ In that year and in the following, Stokes was privately tutored by the famous mathematical coach, William Hopkins (of whom more below).

In addition to the tuition provided by the college, there were lectures delivered by the professors. Not all students attended the lectures of the mathematics professors, and not all of the mathematics professors lectured. While Stokes was an undergraduate neither of the Lucasian professors—Charles Babbage, who held the chair from 1828 to 1839, and Joshua King, who held the chair from 1839 to 1849 (when he was succeeded by Stokes)—lectured. George Peacock, Lowndean professor of astronomy and geometry, advertised lectures on "Science of astronomy and practical methods of observation; use of Instruments. Geometry, and general principles of Mathematical

⁶ The same order would pertain in the Tripos examination in the following year with a student from Trinity, Henry Cadman Jones, coming between them.

Reasoning” some of which Stokes attended.⁷ Stokes also attended the lectures of the Plumian professor of astronomy and experimental philosophy, James Challis (today best remembered for failing to identify the planet Neptune).⁸ Challis offered “Laws of Hydrodynamics, Pneumatics, and Optics with special reference to the Mathematical Theories of Light and Sound. Explanations exhibited experimentally; explanations given of Principles employed in Mathematical Reasoning” [11].

As well as Euclid’s *Elements* and Newton’s *Principia*, there were several mathematical textbooks which Cambridge students were expected to study, many of which had been written by former Cambridge wranglers and were designed specifically for students of the university. Amongst the most prolific and influential of writers who produced books in this category was John Hymers (Second Wrangler in 1826), a fellow of St John’s, who successfully combined his college career with private tutoring, and who examined for the Tripos in 1833 and 1834. With a reputation for being “profoundly versed in mathematics”, Hymers had “a vast acquaintance with the mathematics of the Continent” [12] which was evident in many of his books. For example, the second edition of his *Integral Equations* (1835) introduced English students to the newly discovered topic of elliptic functions, while his *Treatise on Conic Sections and the Application of Algebra to Geometry* (1837) became the standard textbook on analytic geometry.

The 1816 translation of Lacroix’s introductory textbook on the differential and integral calculus by Babbage, Herschel, and Peacock, which was an important stimulus for the introduction of analytical methods into Cambridge, was followed by several new books that treated their subjects from an analytical perspective and became standard undergraduate fare. Among these were the textbooks of William Whewell on mechanics (1819) and dynamics (1823). George Biddell Airy’s *Mathematical Tracts* was another staple text. Originally published in 1826 while Airy was Lucasian professor, the second edition of 1831, which would have been studied by Stokes, included a new

⁷ Stokes Collection. PA34, Department of Manuscripts and University Archives, Cambridge University Library.

⁸ Stokes Collection. PA35, Department of Manuscripts and University Archives, Cambridge University Library.

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section on the wave theory of light. It provided an analytical approach to problems of physical astronomy, the shape of the Earth, and to its precession and nutation, although it was not appreciated by all undergraduates. Robert Leslie Ellis, senior wrangler the year before Stokes, considered Airy's discussion on precession to be "very badly done" [13]. A more advanced text espousing a similar analytical approach which appeared a few years later was John Pratt's *The Mathematical Principles of Mechanical Philosophy and their Application to the Theory of Universal Gravitation* (1836). Pratt (Third Wrangler in 1833), a former student of Hopkins, provided a particularly clear account of the shape of the earth. Another book Stokes may have read is Mary Somerville's *Mechanism of the Heavens* (1831), Somerville's interpretation of Laplace's *Mécanique Céleste*, which was promoted to Cambridge students by Whewell and Peacock [14 p172].

Coaching

Stokes's coach, William Hopkins (Seventh Wrangler in 1822), was the first of the Cambridge coaches to make a permanent living from private tutoring. He rapidly developed a reputation as an outstanding teacher and his results were remarkable. Between 1828 and 1849 he "personally trained almost 50% of the top ten wranglers, 67% of the top three, and 77% of senior wranglers", which amounted to 108 in the top ten, 44 in the first three, and 17 senior wranglers, and earned him the sobriquet 'senior wrangler maker' (14 p84–5). Stokes began studying with Hopkins in his fourth term and stayed with him until his final examinations. Hopkins taught in small classes, putting students of equal ability together, which "meant that the class could move ahead at the fastest possible pace, the students learning from and competing against each other" [15 p84]. Or as one of Hopkins's obituarists wrote:

The secret of his success as a teacher was the happy faculty he had of drawing out the thoughts of his pupils and make them instruct each other, while he took care that the subjects under discussion were treated in a philosophical manner so that mere preparation for the senate-house examination was subordinate to sound scientific training.⁹

⁹ *The Gentleman's Magazine*, 1866, p. 706, quoted in [16 p40].

The system appears to have suited Stokes rather well. He kept the notes he made while reading with Hopkins, although they are rather difficult to read.¹⁰ There are sets of notes for several different courses including differential and integral calculus, mechanics, dynamics, optics, hydrostatics, hydrodynamics, sound and light, and calculus of variations. These give a good idea of Hopkins' style of teaching: the standard theory is given, examples are worked through and others are left for the student to complete.

However, although the efficacy of the teaching of coaches such as Hopkins could not be denied, the system of private tutoring itself had its detractors, particularly during Stokes's time as an undergraduate. Peacock notably regarded it as "an evil of the most alarming magnitude", on the grounds that it undermined teaching within the colleges and the university, and its expense for students [17 p153]. Since a student aspiring to high honours had to engage a private tutor in order to have a real chance of success, the cost of doing so was an important factor in the debate. In 1839 Ellis paid Hopkins £42 for a year's worth of coaching, a fee which indicates that he was being coached six days a week [15 p87]. In 1852 Hopkins himself estimated that to a good student the cost of private tutoring for three years was approximately £150 [18 p100]. Although the Stokes family were not rich, there is nothing to suggest that Hopkins' fees were an issue for Stokes. It is likely that Stokes's brother William, who was a Fellow and Dean of Gonville & Caius College and in receipt of a generous stipend, had ensured that Stokes had no money worries.¹¹

¹⁰ Not only is Stokes's handwriting hard to fathom, but the notes, due to their fragility, are now only available on microfiche. Stokes Collection. PA2-24, Department of Manuscripts and University Archives, Cambridge University Library.

¹¹ *Liber Rationalis 1815-1850*, Gonville & Caius College Archives. William Stokes would have been alert to the importance of coaching, both from his own experience as a wrangler in 1828, and through his friendship with George Green who had been elected to the Caius Fellowship in 1839 [19 p108-109]. Green, who had not been coached, had been tipped to be Senior Wrangler in 1837 but came only Fourth.

Hopkins had a lasting influence on Stokes, and not only a pedagogical one. While Stokes was still an undergraduate, it was Hopkins who advised him to study hydrodynamics [2 p9], the subject in which he began his research.

Examinations

During the early decades of the nineteenth century, the Senate-House Examination underwent a number of reforms. At the beginning of the century it lasted for three days, but it was gradually extended so that by the time Stokes came to sit it in 1841 it was six days, having been extended from five in 1839, with the papers becoming progressively more difficult. The questions were of two types: bookwork and problems. The former required students to reproduce standard definitions, theorems, and proofs, while the latter tested students' ability to apply what they had learnt to increasingly technical and challenging problems. These were not problems to be found in the back of textbooks but problems constructed specifically for the examination, and it was not unusual for the examiners to base questions on their own research [15 p156]. There were two examinations every day apart from Sunday, two-and-a-half hours in the morning and three hours in the afternoon, making a total of thirty-three hours examination altogether. For the first two papers, students were not allowed to use the differential calculus. Every undergraduate had to take the first four papers and a failure to pass resulted in the student being 'plucked'; i.e. not allowed to continue his studies. Importantly, it was the problems, particularly those on the papers in the final days, that effectively determined the order of merit. In 1843, two years after Stokes sat the examination and the year in which John Couch Adams led the field, Thomas Minchin Goodeve, who had been expected to be second wrangler and later made a career teaching mathematics at Kings College London and the RMA Woolwich, survived only the first four days of examination before giving up, but still ended up in ninth place.

The preparation for the examination was a punishing experience and it is little wonder that the health of students was sometimes compromised. The American Charles Bristed, who studied for the Tripos between 1841 and 1844 and wrote a book chronicling his experience, declared:

Indeed a man must be healthy as well as strong—"in condition" altogether to stand the work. For in the eight hours a-day which form the ordinary amount of a reading man's study, he gets through as much work as a German does in twelve; and nothing that our students go through can compare with the fatigue of a Cambridge examination. If a man's health is seriously affected, he gives up honors at once, unless he be a genius like my friend E[llis], who "can't help being first" [20 p331].

Ellis suffered from poor health throughout his time at Cambridge and indeed for most of his life. Stokes was more robust. He told his daughter that "he never read more than eight hours a day, even before an examination" and that "he had never been reduced to binding his head up with a wet towel" [2 p7].

The examination began on the 6 January and finished a week later. The 12 papers contained 175 questions in total. The standard bookwork questions required the reproduction and/or proof of propositions from Euclid's *Elements* and from Newton's *Principia*. For example, the very first

question on the first paper required a proof of Proposition 13 from Book 1 of Euclid's *Elements*, the Proposition itself having been given. By the time students got to the twelfth question on the second paper they were simply asked to "Enunciate and prove the tenth lemma of Newton's first section", showing that they were expected to know the lemma from its number as well as be able to prove it. Other questions were mostly on algebra, the calculus, mechanics, dynamics, astronomy, hydrostatics, and optics, with a few on heat, electricity, and magnetism. The following two problems (of nine) from the twelfth and final paper give an indication of what was expected of the best students:

1. Explain how Newton's method of approximation may be adjusted so as to furnish the real roots of an equation to any required degree of accuracy.
8. Assuming the properties of the axes of elasticity, find the velocity of transmission of a wave of light after refraction at the surface of a uniaxial crystal. If the crystal be bounded by planes perpendicular to the axis investigate the difference of retardation of the ordinary and extraordinary rays. State briefly how it is shewn by experiment that plane and circularly polarized light differ from one another.

The results were announced in the Senate-House on 22 January 1841, ten days after the final examination. As was common practice, the results were widely reported, both in the national press—*The Times* of London regularly printed a full list of the successful students—and in the local press in which often a 'local hero' was celebrated. The reports were also syndicated so that the same report appeared in different local newspapers up and down the country. Several of the early reports wrongly claimed that Stokes was the first senior wrangler from Pembroke, a fact corrected in later editions. Many too considered the fact that the Senior Wrangler was "an Irishman" was a point worth making.

As it happens, the papers that year had been particularly difficult which resulted in a high number of failures among classics students. These failures were widely reported, almost more so than Stokes's success. The *Hull Packet* was typical in taking up the story:

The number of names on the printed list, published previously to the examination, contains 145 names; that on the return list is 117. It must not, however, be taken for granted, that all whose names were on the first list went into the Senate House, and that, consequently, 28 had the misfortune of being 'plucked'. I believe that 25 is the exact number of these unhappy ones,—amongst them are some of the best classics in the University, who are debarred from the privilege of going in for the classical tripos and the medal. For the latter honour, even a junior optime cannot go in. Trinity [College] is like a little town in a roar this morning, on the disagreeable subject of a pair of their best classical scholars (of the house too) being plucked for *plus* and *minus* [21 p3].

The failures, who went to Oxford to recuperate [22 p196], were the subject of correspondence in *The Times*.¹² Bristed too remarked on them [19 p85], as did Ellis.¹³ Later that same year, Peacock voiced his concerns:

The problems which are proposed in the senate-house are very generally of too high an order of difficulty, and are not such as naturally present themselves as direct exemplifications of principles and methods and require for their solution a peculiar tact and skill, which the best instructed and most accomplished student will not always be able to bring to bear upon them. It is not unusual to see a paper of questions proposed for solution in the space of three hours, which the best mathematician in Europe would hesitate to complete in a day. [17 p153]

Given that the statutes explicitly stated that the papers should not contain more questions than well-prepared students could answer within the time allowed, the difficulty of the papers was clearly a legitimate worry.¹⁴

Putting Stokes's triumph in the context of the uproar over the stiffness of the examination gives the description by Joseph Romilly of Stokes as "a very good" senior wrangler extra resonance, especially since Romilly was a Trinity man [18 p45].¹⁵ But Stokes's trials were not over with his victory in the Senate-House Examination.

Shortly after the results had been declared, the top wranglers knuckled down again to compete for the Smith's Prize [23]. This took the form of further examination papers, each one of which was

¹² *The Times*, 28 January 1841, p5 and *The Times* 29 January 1841, p5.

¹³ On 1 February 1841, Ellis wrote in his journal "It is the cry at the moment that too much was exacted from the low men 25 of whom were plucked, among them 4 good classics. There has been a letter in the Times about it, in as bad a spirit as the rest of the paper. The truth is, were the classics out of the way I would raise the minimum very much, to check the foolish rage for going out in honours. The poll examination implies a more useful course of reading than the wretched pumps and pulleys and tadpoles on which the minds of junior optimes are fed." Ellis diaries. Add.Ms.a.82, Trinity College Cambridge.

¹⁴ Concerns about the Tripos eventually culminated in 1848 in the establishment of the Board of Mathematical Studies which then oversaw the examinations, see [15 p94-103] and [18 p66-77].

¹⁵ Joseph Romilly was the Registry of the University from 1832 to 1862.

sat over the course of a day and was set by a different examiner. Unlike the Tripos, the questions were usually geared towards evincing an original or creative approach. In general, only the most distinguished wranglers sat the examination, so the numbers entering were usually small, and it was not unknown for the number of candidates to be the same as the number of prizes.

In 1841 the Smith's Prize examiners were the three mathematics professors: Peacock, Challis, and King. Each paper consisted of around twenty-five questions ranging over a variety of subjects from pure mathematics to the construction of astronomical instruments, and often included a discursive element. Once again, Stokes won the day. Although the prize was worth £25, its real value was in the academic prestige attached to winning. The competition was a much sterner test than the Tripos and although to the outside world a prizeman did not carry the cachet of a senior wrangler, within the confines of the Cambridge mathematical community being First Smith's Prizeman was recognized as the ultimate achievement.¹⁶ It is touching to note that at the Stokes Jubilee,¹⁷ almost 60 years later, the presence of the student who had been second to Stokes in both the Tripos and the Smith's Prize, Henry Cadman Jones, was considered "one of the most pleasing features" of the celebrations [25 p125].

On 23 January, with all the results announced, Pembroke celebrated Stokes's remarkable success by holding a grand dinner in his honour and making him a fellow of the College. The world was now his oyster. As one relative wrote to him, he now had only to determine whether he would be "Prime Minister of England, the Lord Chancellor or Archbishop of Canterbury."¹⁸

¹⁶ Several years later, in 1854, when Stokes, as Lucasian Professor, was responsible for setting one of the Smiths Prize papers, he famously included what is now known as Stokes' Theorem as one of the questions. This was the first appearance of the theorem in print which is why it is usually known as Stokes' Theorem, although Stokes first been made aware of it four years earlier by William Thompson (later Lord Kelvin) so that it is now sometimes referred to as the Stokes-Kelvin Theorem [24 p97]. The paper was sat by James Clerk Maxwell who was the winner of the First Smith's Prize that year.

¹⁷ The Stokes Jubilee marked the 50th anniversary of Stokes's tenure as Lucasian Professor.

¹⁸ Letter from N.C. Fenwick to Stokes, 1 February 1841. Stokes Collection. Add MS 7656. F69, Department of Manuscripts and University Archives, Cambridge University Library.
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