Alex D.D. Craik

Mr Hopkins' Men

Cambridge Reform and British Mathematics in the 19th Century

Springer

A.D.D. Craik

Mr Hopkins' Men

A.D.D. Craik

Mr Hopkins' Men

Cambridge Reform and British Mathematics in the 19th Century

Springer

Professor A.D.D. Craik, BSc, PhD, FRSE
Mathematics Institute
University of St Andrews
St. Andrews
Fife
KY16 9SS
UK

Cover illustrations: Engraved portrait of William Hopkins (courtesy of the Master and Fellows of Peterhouse); Coloured engraving of St. Peter's College, from Ackermann (1815).

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2006940325

ISBN: 978-1-84800-132-9 e-ISBN: 978-1-84628-791-6 Printed on acid-free paper

9 8 7 6 5 4 3 2 1

Springer Science+Business Media
springer.com

To Liz,
who has enriched my life in so many ways.
With much love and gratitude.

Preface

A few years ago, in the Wren Library of Trinity College, Cambridge, I came across a remarkable but then little-known album of pencil and watercolour portraits. The artist of most (perhaps all) was Thomas Charles Wageman. Created during 1829–1852, these portraits are of pupils of the famous mathematical tutor William Hopkins.

Though I knew much about several of the subjects, the names of others were then unknown to me. I was prompted to discover more about them all, and gradually this interest evolved into the present book. The project has expanded naturally to describe the Cambridge educational milieu of the time, the work of William Hopkins, and the later achievements of his pupils and their contemporaries.

As I have taught applied mathematics in a British university for forty years, during a time of rapid change, the struggles to implement and to resist reform in mid-nineteenth-century Cambridge struck a chord of recognition. So, too, did debates about academic standards of honours degrees. And my own experiences, as a graduate of a Scottish university who proceeded to Cambridge for postgraduate work, gave me a particular interest in those Scots and Irish students who did much the same more than a hundred years earlier. As a mathematician, I sometimes felt frustrated at having to suppress virtually all of the fine mathematics associated with this period: but to have included such technical material would have made this a very different book. Despite this limitation, I hope that I have managed to convey something of the intellectual ferment and stunning achievements of the age.

In the course of researching a work of such wide range, I have benefited much from the writings of others, as the large bibliography attests: my debt to them is obvious. To those who provided more direct assistance or useful comments (sometimes without realising it) I am especially grateful. At my home base of St Andrews University, they are Peter Lindsay, John O'Connor, Eric Priest and Edmund Robertson of the School of Mathematics and Statistics; and the staff, past and present, of the Special Collections Department of

St Andrews University Library, especially Robert Smart, Norman Reid, Christine Gascoigne, Moira Mackenzie and Cilla Jackson. I also thank, in alphabetical order, Abhilasha Aggarwal, June Barrow-Green, Tony Crilly, Mary Croarken, Ivor Grattan-Guinness, Kevin Greenbank, David McKitterick, Tony Mann, Julia Mant, Alex May, Maria Panteki, Karen Parshall, Philip Pattenden, Denny Plowman, Adrian Rice, Crosbie Smith, Jonathan Smith, Andrew Warwick, Ronald Wiltshire, Alastair Wood and anonymous Springer referees for helpful remarks, or for help in gathering illustrations. I am particularly indebted to my wife, Elizabeth Craik, both for her constant support and encouragement, and for nobly reading a complete draft of this work and saving me from many infelicities of expression and arrangement. Of course, all errors and omissions are my own responsibility, and I would welcome notification of any that readers may discover.

This work took me to many libraries, where I was assisted by their staff: in London, the British Library, the library of the Royal Society, University College Library and London University's S.O.A.S. Library; in Cambridge, Cambridge University Library, the libraries of Peterhouse, Gonville & Caius College, Trinity College, and Cambridge University's Centre for South Asian Studies; in Edinburgh, Edinburgh University Library.

Various bodies gave permission to quote from books and manuscripts, and to reproduce images. I thank the Master and Fellows of Trinity College, Cambridge; the Master and Fellows of Peterhouse, Cambridge; the Syndics of Cambridge University Library; the Syndics of Cambridge University Press; the Centre of South Asian Studies, University of Cambridge; Special Collections, St Andrews University Library; the School of Mathematics and Statistics of St Andrews University; Library Services, University College, London; Archives and Records Management Services, University of Sydney; Nottingham City Museums and Art Galleries; Higginbotham's Press, Bangalore. Most of the illustrations for which sources are not explicitly acknowledged have been copied from books in St Andrews University Library. (Every effort has been made to seek permissions for quotations and illustrations used in this book: but if any copyright holders have been inadvertently overlooked, the publisher would be glad to hear from them.)

At Springer, Karen Borthwick has been an unfailingly courteous and helpful editor. To her and to her backroom colleagues, I extend my thanks.

Alex Craik

Contents

List of Illustrations

Figures in Black and White

Color Plates (following page 146)

Part I

Educating the Elite

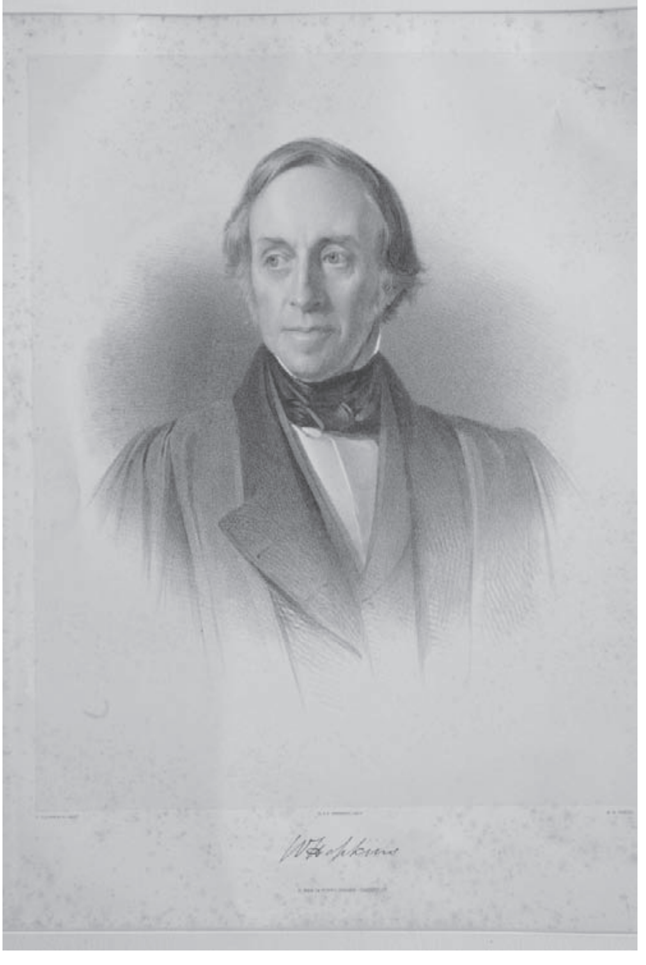


Figure 1. Engraved portrait of William Hopkins circa 1850. (Courtesy of the Master and Fellows, Peterhouse, Cambridge.)

1.

Introducing Hopkins and His Wranglers

William Hopkins (1793–1866) was the first of two remarkable private tutors at Cambridge, who dominated the teaching of the university while remaining detached from the formal tuition provided by the colleges. His outstanding successes were matched only by those of his former student and *de facto* successor Edward J. Routh. Figure 1 shows an engraved portrait of Hopkins, aged perhaps in his mid-fifties. His long face, clean-shaven in a much bewhiskered age, has a rather prominent nose, and his eyes seem clear and piercing below dark brows. An oil portrait of a somewhat older Hopkins, by Henry William Pickersgill R.A. (1782–1875) and now hanging in the Fellows' Parlour in Peterhouse, Cambridge, is reproduced in Plate 1 of Chapter 6. It is recognisably of the same man, tall, dignified, straight, and slim. This may have been painted to mark Hopkins' retirement in 1860.

For much of Hopkins' time, the B.A. (Batchelor of Arts) honours degree was awarded on the sole basis of performance in the Mathematical Tripos examinations. The lists of successful honours candidates were each year divided into three categories, called "Wranglers", "Senior Optimes" and "Junior Optimes". In present-day parlance, these categories correspond to first-, second- and third-class honours. Within each category, candidates were listed in order of merit. The senior wrangler was top of the list, followed by the second and third wranglers, etc. These order-of-merit listings began in 1747 and ceased in 1909.[1]

Table 1 below lists all the senior, 2nd and 3rd wranglers from 1827 to 1860. The start date is the year when Hopkins himself graduated, and he began

[1] Mathematical prerequisites for taking the Classical Tripos were dropped in 1850—see later. Complete Tripos lists for all years and all subjects were published in every edition of the *Cambridge University Calendar* up to 1913–1914, and in Tanner (1917). These give the candidates' colleges and the names of Moderators and Examiners. Partial lists can be found also in Wilson (1985); Barrow-Green (1999), who gives Smith's Prize winners; and Warwick (2003, Appendix A), who supplies the names of the private tutors of many top-ten wranglers, from 1865 to 1909.

Table 1. List of the top three wranglers, and some others, who graduated during 1827–1860

Year	Senior	2nd	3rd	Other
1827	H.P. Gordon	T. Turner	A. Cleasby	A. De Morgan (4th), W. Hopkins (7th)
1828	C. Perry	J. Baily	J.H. Evans	W. Selwyn (6th)
1829	**H. Philpott**	W. Cavendish	R. Murphy	
1830	C.T. Whitley	**J.W.L. Heaviside**	E. Steventon	C. Pritchard (4th), J.M. Heath (27th equal)
1831	S. Earnshaw	T. Gaskin	**G. Budd**	G.E. Paget (8th), C.R. Darwin (poll degree)
1832	**D.D. Heath**	S. Laing	T. Cotterill	<u>H.W. Cookson</u> (7th), R. Potts (26th)
1833	**A. Ellice**	**J. Bowstead**	<u>J.H. Pratt</u>	
1834	**P. Kelland**	**T.R. Birks**	R. Stevenson	<u>R. Main</u> (6th)
1835	**H. Cotterill**	**H. Goulburn**	R. Rawle	S.S. Greatheed (4th), <u>C. Blackburn</u> (8th)
1836	**A. Smith**	**J.W. Colenso**	J.F. Robinson	W. Pirie (5th), W. Walton (8th)
1837	**W.N. Griffin**	<u>J.J. Sylvester</u>	E. Brumell	G. Green (4th), D.F. Gregory (5th), A.J. Ellis (6th)
1838	**T.J. Main**	**J.G. Mould**	**M. O'Brien**	R. Potter (6th)
1839	**B.M. Cowie**	P. Frost	C. Colson	D. Thomson (21st SO)
1840	**R.L. Ellis**	**H. Goodwin**	J. Woolley	
1841	**G.G. Stokes**	**H.C. Jones**	J. Sykes	J. Cockle (33rd)
1842	**A. Cayley**	**C.T. Simpson**	R.B. Mayor	<u>F. Fuller</u> (4th)
1843	J.C. Adams	F. Bashforth	B. Gray	
1844	**G.W. Hemming**	**W.B. Hopkins**	**C.O. Budd**	<u>J.W. Stephen</u> (4th), <u>F. Galton</u> (poll degree)
1845	S. Parkinson	**W. Thomson**	R. Peirson	<u>F.W.L. Fischer</u> (4th), <u>H. Blackburn</u> (5th), J.B. Cherriman (6th)
1846	**L. Hensley**	<u>J.A.L. Airey</u>	F.J. Roughton, A. Sandeman	
1847	**W.P. Wilson**	**R. Walker**	F.W. Vinter	J.B. Phear, 6th
1848	**I. Todhunter**	**C.F. Mackenzie**	**W. Scott**	**A. Barry** (4th equal & 2nd Smith's Prize)
1849	**M.B. Pell**	**H.C. Phear**	**W.A. Porter**	
1850	W.H. Besant	**H.W. Watson**	J. Wolstenholme	
1851	**N.M. Ferrers**	W.C. Evans	**G. Yool**	<u>J. Porter</u> (9th)
1852	**P.G. Tait**	**W.J. Steele**	H. Godfray	
1853	T.B. Sprague	R.B. Batty	C.J. Newbery	
1854	<u>E.J. Routh</u>	<u>J.C. Maxwell</u>	<u>H.R. Droop</u>	

Table 1. *Continued*

Year	Senior	2nd	3rd	Other
1855	J. Savage	L.H. Courtney	C. Elsee	
1856	A.V. Hadley	J. Rigby	C.B. Clarke, J.C.W. Ellis, H.W. Smith	H. Fawcett (7th), B.T. Moore (8th)
1857	G.B. Finch	T. Savage	J.E. Gorst	J. Venn (6th equal)
1858	G.M. Slesser	C.A. Smith	F.C. Wace	
1859	J.M. Wilson	F. Brown, A.W.W. Steel	—	W. Jack (4th), R.B. Clifton (6th), W.G. Adams (12th), W. Besant (18th), A.S. Herschel (20th)
1860	J. Stirling	W. Baily	G. Richardson	

Those in bold were pupils of William Hopkins whose portraits appear in the Wren Library album (and Chapter 6). Other known pupils of Hopkins are underlined.

tutoring soon afterwards. The end date of 1860 is the time of Hopkins' retiral and is eight years after the last entry in the Wren Library portrait album mentioned in the Preface. The names shown in bold type are the forty-two of Hopkins' pupils represented in this album, their images reproduced in the colour plate section of Chapter 6. All came in the first three places, except A. Barry (fourth equal, 1848). We also list some lower wranglers who are mentioned in the following chapters.

No definitive list of Hopkins' pupils has survived, but it is certain that he tutored several others in the Table as well as many lower-ranked wranglers. Those further pupils known (from a variety of sources) to have been taught for a time by Hopkins are underlined, and there are doubtless others. The portrait album contains wranglers for the years 1829–52. But a former University official, H. Gunning, was informed by Hopkins himself that he tutored forty-four senior, second and third wranglers up to 1849, seventeen of whom had been senior wranglers. As five of the forty-one in the album are from after 1849, and assuming that Gunning's information is correct, we have portraits of all seventeen senior wranglers up to 1849, but only nineteen from a possible twenty-seven second and third wranglers.[2]

[2] Winstanley (1940), pp.41, 42; Gunning (1854), v.2, p.359.

Hopkins' most successful year was 1854, with seven of the top nine wranglers, following a particularly poor previous year. The Trinity College fellow Joseph Romilly recorded in his diary that "Hopkins' star is in the ascendant this year: the Senior & 2d & 3d Wranglers, the 6th, 7th, 8th & 9th are his pupils:—last January his highest man was 8th, & his servant is reported to have said of him 'Master an't placed this year!'" He had another poor year in 1857, but in 1858 he believed that his top pupil, Smith, could not be beaten. However, E.J. Routh's pupil, Slesser, narrowly did so—an intimation of Routh's later dominance. In 1863, just three years after Hopkins' retiral, Routh coached an unprecedented nine of the top ten wranglers, including the senior wrangler. Routh went on to tutor *all* of the top ten wranglers in both 1865 and 1874, and nine of ten in 1881.[3]

But Hopkins' influence was far greater than that which a successful private tutor exerts upon his own pupils: he had a profound effect on the teaching of mathematics throughout Cambridge. He influenced the content of the examinable courses, he advocated reforms of the University, and his example as a tutor set the standard to which others aspired. During Hopkins' thirty-year career as the best private tutor for able students, the Mathematical Tripos evolved as an ever more rigorous test of both talent and endurance, and the reputation of Cambridge mathematics rose from mediocrity to rival the best in the world. *All* the wranglers of this period were influenced by Hopkins in one way or another: directly or indirectly, they were all "Mr Hopkins' men". For that reason, the scope of this work is not restricted to those known to have been taught by Hopkins.

As might be expected, a substantial minority of top wranglers went on to become professional mathematicians and scientists, and these include some of the greatest names of their generation. Those who made the greatest mark in research are G. Green, G.G. Stokes (later Sir George Stokes), W. Thomson (later Baron Kelvin of Largs), J.C. Adams, A. Cayley, J.J. Sylvester, P.G. Tait and J.C. Maxwell. Noteworthy contributions were made also by I. Todhunter, P. Kelland, D.F. Gregory, R.L. Ellis, N.M. Ferrers, M. O'Brien, A. Smith and E.J. Routh. Stokes and Thomson both became Presidents of the Royal Society of London; Thomson and Kelland were Presidents of the Royal Society of Edinburgh. H. Phillpot, Ferrers and Stokes became heads of Cambridge colleges, and Ferrers and Philpott served periods as Vice Chancellor of the University. T.R. Birks became Professor of Moral Philosophy at Cambridge, and G. Budd Professor of Medicine at King's College, London. Several others became

3 Bury & Pickles (2000), pp.167, 269, 306; Warwick (2003), Appendix A.

professors of mathematics, natural philosophy or astronomy in Britain and Australia. W. Cavendish, a member of the nobility, duly became the seventh Duke of Devonshire and served as Chancellor of Cambridge University during 1861–92: his generous donations enabled the establishment of the Cavendish Laboratory and the subsequent rapid growth of experimental science at Cambridge.

Some attained high office in the Church of England, at home or in the Colonies. Of these, H. Philpott, R. Rawle, A. Barry, J.W. Colenso, H. Cotterill, H. Goodwin and C.F. Mackenzie all became bishops—though Colenso was later excommunicated! J.H. Pratt was archdeacon of Calcutta, and several other churchmen were deans of English cathedrals. Other wranglers had prominent legal and political careers, and a few managed to combine religious or legal pursuits with mathematical and scientific interests. Some had less-prominent but worthy lives as vicars and rectors of rural parishes, lawyers, and educators. A few died young, promise unfulfilled. Only one, C.O. Budd, went into "trade", as a wine merchant.

In the course of this work, many questions arose about Cambridge's role in preparing these men (or not) for their later careers. Was the all-out competition for success in the Mathematical Tripos examinations a uniquely appropriate training for the struggles of later life? Did the emphasis on mathematics engender a rational, logical and moral attitude of mind, as some claimed? Or did these examinations inhibit creativity and imagination while rewarding memory and parrot repetition? To what extent was later career success attributable to preferment and patronage? Why were so many of the best scientists Scots and Irish? And why did so few contribute to the great trading, industrial and technological expansion of the Victorian age?

Christian belief and observance ordered the lives of these men and interacted with their scientific pursuits: then, most scientists were actively involved in religious affairs, and churchmen were well informed about science. They were among Britain's brightest students of the mid-nineteenth century, and in later life they debated the scientific and religious controversies of the age. They participated in a web of friendships, collaborations and disputes; and they left a mass of educational, biographical and scholarly writings that define much of the intellectual history of the nineteenth century.

The next three chapters mainly concern Cambridge University: the experiences of its students and fellows, its place in the wider community, the widespread calls for reform that culminated in the 1850 Royal Commission, and the development of the Mathematical Tripos. The scope then widens, both geographically and intellectually. Chapter 5 describes William Hopkins' life as a teacher and researcher, and examines his writings on science and education. Chapter 6 concerns many of Hopkins' top pupils, their youthful portraits preserved in the album that Hopkins once owned. These portraits are reproduced, most of them for the first time, along with brief biographies of the subjects.

Part II (Chapters 7–13) examines the later careers of top wranglers in science, education, the Anglican Church, politics and the law. Perhaps the majority were taught by Hopkins, but Part II is not restricted to those known to have been his students. Many wranglers went on to hold influential positions in universities and colleges throughout England, Scotland, and to lesser extent Ireland (Chapter 9); the activities of others extended beyond Britain to the colonies in Australia, India and Africa (Chapter 10); the most original helped to build a thriving research community in the mathematical and physical sciences (Chapter 11), and many of their scientific and mathematical discoveries remain important today (Chapter 12).

2.

The Student Experience, 1820–1860

Main Contemporary Sources

Evidence of student life in the unreformed university comes from a variety of sources, official and unofficial. Of several first-hand accounts by students, the most notable is that of the American Charles Astor Bristed, whose book, *Five Years in an English University* (Bristed 1852), was published in New York to describe to his compatriots just what university life in England was like. Bristed's book has been described as "the most detailed and the most thoughtful memoir of Cambridge undergraduate life ever penned."[4] Rather earlier student recollections are those of Solomon Atkinson and his near-contemporary John M.F. Wright, who took the Tripos examinations in 1821 and 1819, respectively.[5]

John Venn was equal sixth wrangler in 1857 and later became the President of Gonville & Caius College, a post second only to the Master. His book *Early Collegiate Life* (Venn 1913) concludes with a delightful appendix on "College Life and Ways Sixty Years Ago", vividly describing his own student experiences in the 1850s. The writer Sir Walter Besant also makes interesting remarks on his education, first at King's College, London and then at Cambridge during the 1850s (Besant 1902). By way of introduction, we use the writings of Atkinson, Wright, Bristed, Venn and Besant to illustrate student life and students' views of the university: two from just before the period of Hopkins' wranglers, and three towards its end.[6]

---

4 Searby (1997), p.585.

5 Atkinson (1825a,b,c; 1827); Wright (1827).

6 Searby (1997) reviews Bristed's memoir and also the later description by another American, William Everett (1866). Among other contemporary accounts, those of John Delaware Lewis (1850) and Leslie Stephen (1865) were both written to amuse, making fun of wranglers, tutors and rowing men alike: these contain some interesting comments but less factual information. The recently published letters of Alexander Chisholm Gooden, a Trinity student who was Senior Classic in 1840 (Smith & Stray 2003), paint a picture of college life similar to, if less vivid than, that of Bristed.

The more comfortable lives of college fellows and university officials are illumined by extracts from a rather different contemporary source. Joseph Romilly was a Fellow of Trinity College and, during 1832–61, held the post of Registrary at the University. This important position involved a prominent role at University ceremonies, the collection of fees, and the maintenance of official records. Romilly's private diaries, never intended for publication, are an invaluable informal source of information and opinion that complements the official university and college records. These diaries fill forty-one notebooks covering the period 1818–64, and copious extracts from them have now been published.[7] Quotations from Romilly's diaries are dispersed through several sections of this book. So, too, are extracts from the letters of several students, including William Thomson, Francis Galton and James Clerk Maxwell.

The Struggles of Solomon Atkinson

It is remarkable that Solomon Atkinson got to Cambridge at all, let alone graduate as senior wrangler. His "Struggles of a Poor Student Through Cambridge", and two more articles, were published in the *London Magazine*.[8] Even allowing for some literary exaggeration, his background was a disadvantaged one. The son of a poor Cumbrian farm worker, the young Solomon tended sheep and cattle, made hay and gathered potatoes: though getting some education at the village school, he studied mostly on his own. An appeal to his estranged maternal grandfather, "a man of wayward and singular disposition", gained him £100 to attend university; and Atkinson screwed up his courage to approach Isaac Milner, the Dean of Carlisle who was also the head of Queens' College, Cambridge. Milner was impressed by the young man, and recommended that he apply to Queens', rather than to Trinity or St John's as had been Solomon's ambition. But he warned him that he had no hope of gaining a fellowship at Queens'.

Atkinson was admitted to Queens' in June 1816, as a sizar. He soon encountered the rapaciousness of his "gyp" (college servant), cook's boys, and college tradesmen: "a set of cringing, knavish varlets, that would stoop to any meanness to empty the pockets of a gownsman."[9] Nevertheless, for Atkinson "The

[7] Bury (1967); Bury & Pickles (1994; 2000).

[8] Atkinson (1825a,b,c).

[9] A "sizar" was a needy student supported by the college: so too had been Isaac Newton in his first year at Trinity College. In earlier times a sizar had to perform mundane chores for his better-off peers. The term "gyp" is derived from the Greek for "vulture", in recognition of their notorious habit of soliciting tips and other benefits.

whole scene was . . . an enchantment", though he was much disappointed by the instruction offered:

> I had formed a very high conception of the interest and importance of college lectures. But I was disappointed, wretchedly disappointed, and so I believe is every man who ever heard them. They are in general little more than a kind of desultory conversation,—meagre, unconnected, and barren, as can well be imagined. In nineteen cases, therefore, out of twenty, they are attended merely because attendance is required by the College. . . . To a reading man the lecture-hours are so much time wasted,—to the non-reading men, who merely sit in a corner picking their nails or sketching a caricature, they are a most intolerable nuisance. . . .
>
> Beyond this, I cared little for the matter; I had never relied on the instruction of others, and therefore I did not feel the want of it.

He describes how a student aiming for honours usually seeks private instruction, which adds £100 a year to his expenses; and he suggests that a college tutor who is also a private tutor "must reserve . . . his most valuable information. To act otherwise would take away one half of his pupils." Though the system was too lucrative to be abandoned, it favoured the rich student over the poor, and gave an unfair advantage in examinations where the tutor was also an examiner.

Furthermore, such "pupilizing" also harmed the tutors, inhibiting them from undertaking original work. On becoming fellows and tutors,

> it is a pleasant thing to dictate to a perpetual round of young men of talent and wealth; they are accumulating large fortunes perhaps, if their love of wine parties and gay suppers does not lead them beyond their earnings, which is a very common case, even with the most popular tutors,—they acquire habits of indolence. . . .

After a residence of twenty years, some fellows had gained little learning: instead of a "vigorous, searching, and intelligent mind . . . they are mere undergraduates, mere algebraists". In his view, the past thirty years had produced no intellectual titans like those of the past, who "have been succeeded by a degenerate and pigmy race".[10]

---

[10] The above quotations are from Atkinson (1825a), pp.501–503. Some other acute but uncharitable remarks about individual mathematicians are quoted in the next chapter.

Though academically successful, Atkinson's own university career was marred by unwise decisions. After a year at Queens', he migrated to Trinity, forfeiting a Queens' scholarship for his second year. He probably did so in hope of obtaining a Trinity fellowship on graduation, having confirmed Milner's prediction that he would not get one at Queens'. But he quickly fell into debt, and was forced to take private pupils. Even after gaining a scholarship in his third year, he was unable to afford a private tutor to prepare for the Tripos.

The students from St John's were favourites for top honours, and during the summer vacation they "retired together into Wales with Mr G—n [Gwatkin]" to prepare, while Atkinson worked on his own in Cambridge. Atkinson describes how, as the January examinations approached, "when every minute should have been treasured up, I practised on the flute several hours a day" and continued to take private pupils. Nevertheless, to much surprise, he "carried off the single diadem of the Senior Wrangler" and was awarded the second Smith's Prize.

Despite his success, Atkinson quickly became disillusioned:

> I had expected that the knowledge which led to these distinctions would have served me when . . . I came to associate with men and take a part in the business of life. That knowledge never has served me. I have found it an useless acquirement, and the period of my academical studies an entire blank in the history of my life. Nor was it merely useless; I imbibed, in common with every other man who engages in the strife of University studies, prejudices that were pernicious, absurd, or ridiculous when put to the touchstone of common sense. I had not therefore merely wasted my time. I had learnt that which it was necessary to unlearn as fast as possible.

Instead of acquiring potentially useful information, he had wasted time "marshalling mathematical symbols, which in the process did not discipline my mind, and which . . . did not prepare it for any useful and active occupation."[11]

Though exaggerated for journalistic impact, there was much truth in his strictures. At that time, there was no great demand in the world at large for advanced mathematical skills, and the Cambridge system certainly did not encourage development of any others, apart from the classical languages. As a senior wrangler, Atkinson might easily have followed the common route to

[11] Atkinson (1825a), pp.501, 492.

a Church living or a headmastership, via a Trinity fellowship; but, soon after graduation, he debarred himself from a fellowship by marrying, and he did not wish to remain as a private tutor. Though his wife's family were fairly well-to-do, they disapproved of the match and refused any support.

Almost penniless, the couple moved to London, where Atkinson joined Lincoln's Inn as a lawyer's apprentice. But his wife developed consumption (tuberculosis) after eight months, and, according to Atkinson's account, was forcibly removed by her family into their care. He turned to writing for magazines and encyclopaedias, but with little success; and then took a steerage passage to New York. After a few months, he returned as poor as before, and virtually begged his way back to his Cumberland home.[12]

Another article in the *London Magazine* (Atkinson? 1827) entitled "The Regrets of a Cantab" is probably also by Atkinson. This is a less autobiographical piece, making general criticisms of the Cambridge system. The author again overstates his claim that too much mathematical study stultifies the mind, and that he has acquired no knowledge of the arts: "All the world except myself, seems to abound in ideas; and I have but one", while "female society is to me a blank." At Cambridge, he alleges, more appropriate and useful objects of study are neglected:

> the churchman learns neither theology nor religion; the lawyer neither law, history, ethics, nor that logic which must form his logic; nor do they cultivate their own language . . . far less that rhetoric and that oratory on which the professions, both of the church and of the law so naturally depend. That the future physician learns neither physic, anatomy, botany, chemistry, nor pharmacy, nothing of all that constitutes his science and enables him to practice his art, is more than notorious . . . he must go elsewhere to learn everything that is essential.

He wonders how mathematical science qualifies a man as a statesman, legislator or government officer, while he feels unfit to become even a treasury clerk. If the University will not "reflect that its duty and business . . . is, to educate

[12] Atkinson (1825b). In fact, Atkinson resumed his legal career with some success: he was called to the Bar in 1827 and later published several legal works. These include two short works on the effects of free trade (1827); three editions of J. Chitty's *A Practical Treatise on the Stamp Laws* (1829, 1841, 1850); and several books: *A Practical Treatise on Conveyancing* 2 vols. (1829); *The Conveyancer's Manual* (1830); *The Theory and Practice of Conveyancing* (1839); *An Essay on Marketable Titles* (1833); *The County Court Extension Act . . .* (1850); and *The Law and Practice of the County Courts Under the Insolvency and Protection Acts* (1850). He died in 1865.

young men so that they may be fit to the professions . . . our parents at least might ask themselves this question before they send us to waste our time and money. . . .” Despite the university’s emphasis on mathematics, he asserts that only one in two thousand becomes a *real* mathematician.[13]

Not only was their education deficient: “young men arrive at Cambridge from the public schools, with very doubtful morals . . . it is but too notorious and lamentable that the university is an extensive school of vice and profligacy under all their forms.” Rather than waste their time at Cambridge, young men should seek practical training useful for real life. Declaring that “London is the real university”, the writer means the growing metropolis, the university of life, not the planned London University which had yet to open.

A year later, yet another highly critical article entitled “The Cambridge University Senate-House Examination for Degrees” appeared in the same *London Magazine* (Anon. 1826). The author is unknown: though Atkinson cannot be ruled out, the magazine’s editor seems more likely. The running head for most of the article is “Education of the Many”. The author asserts that, for most Cambridge students, a proficiency in the common rules of arithmetic, the simpler operations of algebra and four books of Euclid’s geometry are all that is expected or required. These, “the Many” or *hoi polloi*, are the “poll men”, whose “mass is nine or ten times greater than those who take honours creditable to them”, and three or four times the number of all honours graduates. For these men, who learn little, cheating and copying in examinations were common in order to scrape a pass: thus “the intellectual interests of more than two hundred students are annually sacrificed to those of some ten, twenty, or, on the most liberal allowance, thirty individuals.” Not only does the University “mistake fellowships and honours for the ends of study, and . . . neglect the majority who resort to her merely to be educated;—she does not appear to consider herself in the slightest degree responsible for their education.”

The writer believed that external criticisms from Scotland had not helped; for, “Aided . . . by the smears of Professor Playfair and his brethern, the calculus has triumphed, and the Edinburgh reviewers may enjoy the consolation

13 Atkinson (1825c), quotations from pp.438, 439, 444, 445. His “1 in 2000” estimate seems only slightly ungenerous, if, by a “*real* mathematician” Atkinson means someone who makes a major original advance in the subject. About 300 students then graduated each year, roughly 100 with mathematical honours, high or low. Atkinson’s estimate therefore allows one outstanding and productive talent every seven years, or about six in forty. Which of the researchers from our list of wranglers would qualify? Green, Sylvester, Cayley, Stokes, Thomson, Tait and Maxwell have the strongest claims and they are seven in number.

of having contributed, by their criticisms, to make a bad institution worse than it was before”. But he allowed that education of “the many” was better organised in the Scottish universities. Thus, at Edinburgh, the Athens of the North, “of the great multitude of dingy Athenians who fill the lecture rooms of their clumsy Parthenon, scarcely *fifty* go away [each year] *without* a competent share of philosophical erudition”, while at Cambridge “not above *fifty* leave *with* a competent portion of philosophical, or any other description of knowledge.”

Opponents of the planned London University had claimed that, among potential students from humble backgrounds, not one in fifty could actually succeed; yet Cambridge was no better than this at providing a real education. The writer urged the fledgling London University to “heed the Quarterly Reviewer’s injunction to disdain all ideas of comparison with the English Universities” in favour of the Scottish model. “The aristocracy will then have some chance of arriving at the enviable distinction of being the only ill-informed and ill-educated portion of the community.”[14]

The Trinity Hall fellow Leslie Stephen also strongly opposed Cambridge’s concentration on mathematics and classics as a kind of mental gymnastics. He believed that, except for the very best students, “nothing can be more absurd than to make five hundred young men . . . give up three years to read classics and mathematics for their own sake. Perhaps fifty of them may be improved by such a discipline. . . . The ‘gymnastic theory’, as applied to those below first class, is a mere farce.”[15]

The extent to which these polemical blasts were justified is a matter addressed in Chapters 3 and 4. They vividly exemplify the discontent with the Cambridge system that eventually led to reform towards the end of our period.

J.M.F. Wright’s “Alma Mater”

John Martin Frederick Wright was admitted to Trinity College in 1813 but did not begin his studies until 1815. Though a competent mathematician who might have been a high wrangler, he fell foul of a regulation that prevented him from competing in the Tripos examinations, and ended up with an *aegrotat* degree in 1819. With no hope of a fellowship, he stayed

[14] Anon. (1826), above quotations from pp.293, 296, 303, 309, 313, 314.

[15] Stephen (1865), p.182.

on in Cambridge, earning what he could as a private tutor and publishing self-help texts of notes and examples.[16] He even launched a weekly magazine, *The Private Tutor and Cambridge Mathematical Repository* (Wright 1830–31) designed for students who could not or did not wish to afford a private tutor. But this probably had little success, for private tutors were becoming indispensable.

His two-volume *Alma Mater*, issued anonymously (Wright 1827), purports to be a comprehensive guide to the University for those who wish to study there or send their children. It is also intended as a defence of the University against some of the criticisms levelled by the popular journals. According to Wright, John Playfair's criticisms in the *Edinburgh Review* revealed his lack of knowledge of Cambridge; but the recent writers in the *London Magazine* deserved greater respect, "being distinguished members of the Institution they have thought fit to calumniate." Aware that Atkinson wrote at least some of these pieces, Wright asserts that the author was, by his "*own fault*, excluded from the emoluments of the University", and now, without a fellowship, was reduced to deriding the source of all the knowledge he possessed in order to earn a living. Later, Wright criticises "Solomon" (without mentioning his surname) as "gifted with as vigorous an intellect as any I ever fell in with, and yet, as to the imaginative, inventive faculties, as barren as the desert", a fact not to be blamed on the study of mathematics.

But Wright's own polemic undermines his credibility. Trying to establish Cambridge's superiority, he launches a diatribe against Scottish education, Scots generally, and their involvement with the new London University. Yet these overstated views doubtless reflect some attitudes current at this time, and they deserve exposure as such:

> Every Cantab . . . knows full well, from the specimens every year exhibiting at College, that the Scotch are a nation of pedants.—They skim the surface of literature, indeed, but never reach its bottom. . . . If you fall in with a Scot, you get hold of a bore and a pedant; who, first taking you for swine, casts his small stock of pearls before you, without mercy; and then, upon

[16] He appears simply as "John Wright" in Venn & Venn (1940) and in Rouse Ball & Venn (1911). Searby's (1997), p.120 account is based on Wright's own [Wright (1827), v.2, pp.46–97]. According to this, Wright missed a preliminary "act" or disputation in his third year, claiming to have been gored by a bull. On learning that this debarred him from taking the full Tripos examinations, he quarreled with Peacock, the examiner, and withdrew from the Tripos. On being "gulphed" by the examiners, he was fortunate to be given an *aegrotat* degree. Warwick (2003), p.547, gives a full list of Wright's self-help texts.

> your turning round upon him, and exposing the scantiness of his information, amuses you with a flaming account of the Latinity of ploughboys, and milkmaids wooing in pastorals of Virgil; tells you the story of the admirable Crighton, . . . and ends with a pompous rigmarole, about the wealth, honours, and erudition of Aberdeen, St Andrew's, Dumfries, Glasgow, and Edinbro'.
>
> . . . During the seven years I resided at Cambridge, [I] cannot recall a single instance of a Scotchman, Scottishly educated prior to his entrance here, having succeeded to the honours or emoluments of Trinity.

As for the projected London University, this is "fathered by Campbell [the poet] . . . fostered by Brougham and Dr Birkbeck the physician—Scottish all." Consequently, all the major posts there will be filled by Scotsmen and dissenters. "Scotticism, Dissenterism, and Radicalism were never so closely united . . . the only learning to be had for your subscription will be a 'mouthful', whilst a 'bellyful' of disaffection to Church and King will be crammed into you gratuitously."

Wright padded his two volumes with reprints of college, Tripos and Smith's Prize examination papers, lists of prizes, exhibitions and scholarships, information on the fellowships at each college and their rules, lists of the salaries of lecturers and professors (not always accurate), and headmasterships and Church livings in the gift of each college. He observes that the seventeen colleges had no fewer than 294 Church benefices in their gift, worth about £300 each on average. His estimate of the total of all college receipts for maintenance of professors, fellows, scholarships, benefices, etc. amounted to about £300,000 per annum, which he tellingly observes is equal to the "*principal*, clubbing for by the signatories of the London University."[17]

Wright's book was the subject of a hostile, also anonymous, review in the *London Magazine*. It states that Wright (identified by name), "After an unsuccessful residence at Cambridge . . . has been driven to seek his livelihood among the booksellers of London"; that his book is "the scrapings of the author's life, collected industriously, for the laudable purpose of getting a dinner." As for Wright's criticisms of the Scots and of London University, "the men whom Alma Mater does not blush to own, would not entertain such opinions." Surely the reviewer was none other than Solomon Atkinson.[18]

[17] Wright (1827); above quotations from v.1, pp.v–vi, 151, 134, 136, 138–140; v.2, p.205.

[18] Atkinson? (1827); quotations from pp.441, 454.

Reminiscences of John Venn, Charles Bristed and Walter Besant

John Venn (1834–1923) graduated in 1857 as equal sixth wrangler. He was an able mathematician and philosopher who made significant contributions to mathematical logic and to what later became known as set theory. He published three treatises on logic, and he was elected a fellow of the Royal Society of London in 1883. From about 1890, he was an indefatigable historian of Cambridge University: he published a six-volume biographical history of Gonville & Caius College (Venn 1898), and he began work, later completed by his son J.A. Venn, on the multi-volume register of Cambridge students, *Alumni Cantabrigienses* . . . (Venn & Venn 1940) which is of great use to historians. His *Early Collegiate Life* (Venn 1913) mainly concerns much earlier times, but concludes with personal reminiscences of "College Life and Ways Sixty Years Ago".

Walter Besant (1836–1901) was eighteenth wrangler in 1859, and worked briefly as a mathematics master at Leamington College. He moved to become a professor in the exotic location of the Royal College, Mauritius, where he embarked on his writing career. Returning to England after six years, he went on to write several successful novels and many other biographical and historical works, notable for their advocacy of social reform. He was knighted in 1895 for his charitable work. (His older brother, William H. Besant, was the senior wrangler of 1850 and a fellow of St John's.) Walter Besant's *Autobiography* (Besant 1902) describes his time as a student at King's College, London and at Christ's College, Cambridge.

In contrast, Charles Astor Bristed (1820–74) was an outsider, an American student whose father had emigrated from England in 1806. His time as an undergraduate at Trinity College during 1840–44 provided the material for his book *Five Years in an English University* (Bristed 1852).

On college teaching, Venn (1913) observed that "The inter-collegiate system was as yet unknown. . . . Outside Trinity and St. John's there was probably not a single College which provided what would now be considered the minimum of necessary instruction, even in Classics and Mathematics." In his own Gonville & Caius College:

> outside this narrow range all was a blank. Theology, for instance, was represented by a good-natured mathematician—his good nature being the cause of his accepting a post declined by his colleagues . . . his grotesque attempts at comment and interpretation . . . were the joke of the College.

In lectures on classics and mathematics, brilliant scholars from the best schools sat next to complete beginners,

> and tried to make the most of the lecture, or at any rate of the time during which the lecture was delivered. . . . It compelled every student, practically, to resort to a private tutor, for the lecturers, as a general rule, gave no assistance whatever out of their official hours. In fact, as they were very frequently private tutors as well . . . it could hardly be expected that they should do so. I feel confident that I never received a single word of advice during my whole time from the tutor, unless it was what church I had better attend or avoid.
>
> I feel as certain as one can be that during my first two years I never had a word of private conversation with any authority of this College as to my studies, and equally sure that I never paid an informal visit to any Fellow's rooms.[19]

Clearly, nothing much had changed since the days of Atkinson and Wright, more than thirty years earlier.

There was little female company, of course: Venn could recall only three or four occasions when, as a student, he "was introduced to ladies' society . . . and these were not exactly lively functions." The formality of university society is exemplified by his visit to two female cousins, briefly staying with William Whewell and his wife at the Master's Lodge in Trinity College. Despite having already graduated as M.A. some five or six years earlier, Venn was advised to wear his academic gown in the Master's presence: he refused to do so, and next day "received a serious remonstrance from my cousin, evidently inspired by the Master."

College accommodation for most undergraduates was spartan and the meals relentlessly unimaginative, apart from those of a few members of the nobility who lived in some luxury at extra expense. Dinner was at 4 or 5p.m., where "Nothing was regularly provided . . . but joints, potatoes and cabbage . . . we did all our carving for ourselves . . . the wasteful hacking . . . which ensued may be conceived. . . . Sweets and cheese had to be specially ordered. Soup, fish and game were absolutely unknown." But beer, and probably wine, was readily available, and "such a thing as a 'teetotaller' was not to be seen or heard of in the whole College." The college servants, too, risked intoxication, owing to the "pernicious practice . . . of giving beer orders . . . payable (in beer) to the bearer".[20]

[19] Venn (1913), pp.256, 258, 259, 263.

[20] Venn (1913), pp.266, 270, 271.

Charles Bristed also commented on the crowd and confusion of the student tables at Trinity College dinner, which he likened to steamboat meals in the U.S.A. Except at the Fellows' high table, "The attendance [service at table] is also very deficient and of the roughest sort."[21]

Venn recalls that his college had no running water, the whole supply coming from hand-pumps operated mainly by the gyps or bedmakers. When a piped water supply was eventually introduced on construction of the town water-works, the college experienced its first typhoid epidemic. In winter, the jugs of water delivered to the rooms sometimes froze solid, a situation that lasted for *several weeks* in the hard winter of 1854–55. The construction of partitions between rooms was often flimsy, and Venn remembered a man who had thrown his sponge though the wall of his room, so hard had it frozen. If typhoid was not a risk until piped water arrived, smallpox certainly was: Venn caught a mild dose in college, but thankfully it did not spread though precautions were rudimentary. In addition, scarlet fever, consumption (tuberculosis) and influenza claimed lives, and the possible spread of occasional cholera outbreaks from other parts of England was much feared.[22]

The physical activities of students had changed much during Venn's lifetime. When he was a student, walking, not cycling, was the norm, and long afternoon walks were the commonest form of exercise. Some rowed on the river, and there was some cricket. But "Lawn tennis and croquet were unborn. Real tennis and hunting were of course confined to the wealthy few. Hockey and football were left to boys." As a student, Venn never saw rugby played; but he relates his younger brother's account of a new game from Rugby school, where "they all made a circle round a ball and butted each other."[23]

Walter Besant entered Christ's College, Cambridge in 1855 after a year at King's College, London. Despite winning several prizes at King's, he had a low opinion of that college: the professor of mathematics [T.G. Hall] "was old and had quite lost all interest in his work", and Besant could "never remember a single word of personal interest or encouragement" from any of the staff. But he believed that "it was much the same thing at most colleges of Oxford and Cambridge at this time. The men were left severely alone; so that, after all, King's was not behind its betters."

At Christ's, Besant enjoyed the close-knit society of a small college, with only fifty or sixty students altogether. He believed that a very large college like Trinity offered fewer social and educational advantages. There,

---

[21] Bristed (1852) v.1, p.26.

[22] Venn (1913), pp.272, 273.

[23] Venn (1913), p.280.

> a man may be simply swamped . . . ; if a man does not belong to any of the great public schools, he will find it difficult to get into certain sets which may be intellectually the best. . . . If he does not distinguish himself in any branch of learning, if he does not do well in athletics, if he shows no marked ability in any direction, it is quite possible for him to go through Trinity as much neglected and alone as a solitary lodger in London.

Though he enjoyed the company of his fellow students, Besant thought poorly of many college fellows at the smaller colleges, who had been appointed before the very recent introduction of open competition, having achieved a place "somewhere among the wranglers." They were typically

> from some small county town; they had a very faint tincture of culture; they were quite ignorant of modern literature; they knew absolutely nothing of art. As regards science, their contempt was as colossal as their ignorance. They vegetated at Cambridge; their lectures were elementary and contemptible; . . . they divided the posts and offices of the college among themselves; they solemnly sat in the Combination Room for two hours every day over their port, . . . and they waited patiently for a fat college living. . . .
>
> The dulness [sic], the incapacity, the stupidity of the dons brought the small colleges into a certain contempt. The decay of Cambridge as a place of learning threatened to overwhelm the University. I believe that for the first half of the century the scholarship and science at Cambridge was a laughing stock on the Continent.[24]

Charles Bristed was taken aback by the sexual and moral attitudes prevalent in Cambridge, about which Venn and Besant are discreetly silent. Soon after his arrival at Trinity, Bristed had been shocked by the suggestion of a fellow student, whom he had only recently met, that they go together to Barnwell to visit a brothel:

> The American graduate who has been accustomed to find even among irreligious men a tolerable standard of morality and an ingenuous shame in relation to certain subjects, is utterly confounded at the amount of open profligacy going on all around him at an English University, a profligacy not confined to the "rowing" set, but including many of the reading men and not altogether sparing those in authority. There is a careless and

[24] Besant (1902), quotations from pp.79–82.

> undisguised way of talking about gross vice, which shows that public sentiment does not strongly condemn it.
>
> That shop-girls, work-women, domestic servants, and all females in similar positions, were expressly designed for the amusement of gentlemen, and generally serve that purpose, is a proposition asserted to by a large proportion of Englishmen, even when they do not act upon the idea themselves.[25]

The reference here to "rowing" men does not mean oarsmen, but high-living, *rowdy* students, who contrasted with the "reading men" intent on acquiring an education.

Bristed's criticisms are supported by R.M. Beverley, who wrote (of a somewhat earlier period) that:

> It is the nightly work of the Proctors to clear the brothels of the undergraduates, and Castle-end and Barnwell are constantly visited for this purpose. It was no uncommon thing in my day to make a party to go up to Castle-end immediately after the Sunday-evening chapel. It was the fashionable evening for such expeditions.[26]

Bristed's comments on other aspects of life at Cambridge, notably college teaching and private tutors, reinforce the views of Atkinson and Venn already quoted. Regarding morals, neither Bristed nor any other of our witnesses says anything about the prevalence, or otherwise, of homosexuality in or outside the colleges. Such activity was against the law, and regarded as a sin by all religious denominations. It was simply not written about nor openly admitted, though, like prostitution, it was probably tolerated and ignored unless offence was caused. Given the unchanging character of human nature, and the all-male society of the colleges and of the public schools which many of the boys had attended, it is hard to believe that the incidence of homosexual practice was much lower than it is today. But little evidence exists.

The laxity of moral attitudes certainly worried the parents of students, if not the mass of students themselves. An anonymous pamphlet "by An Anxious Father" (Anon. 1850) complained about the culture of extravagance, debt, gambling, hunting, etc. This father hesitated to send his son to train for the Church in such a place, citing the case of the son of a relative who ran up huge debts over two years. He urged the authorities to take immediate action

---

[25] Bristed (1852), v.1, pp.40, 47, 48.

[26] Beverley (1833), p.13.

to put their house in order. Similar views had earlier been forcibly expressed by Robert Mackenzie Beverley, in a published 1833 address to the Chancellor of the University. As well as citing examples of extravagant and immoral behaviour of students, he accused college fellows of similar depravity. Beverley had some local knowledge: he had been an undergraduate at Trinity College during 1816–20, before becoming a Dissenter and an outspoken critic of the Church of England. Among several replies in defence of Cambridge against Beverley's "scurrilous pamphlet", those from Professor Adam Sedgwick carried most weight. Though admitting that some misdemeanors undoubtedly occurred without the knowledge of the authorities, Sedgwick tried to reassure the public that most cases came to their attention and were appropriately dealt with. But Beverley persisted with his damaging allegations.[27]

Joseph Romilly's Diaries

Joseph Romilly (1791–1864) was an ordained priest and fellow of Trinity College, who conducted occasional services, baptisms, marriages and funerals around Cambridge. But his main duties were as Registrary of the University of Cambridge, a post that put him at the heart of the running of the university.

In his diaries, Romilly indefatigably recorded his official and social activities, trivial and important, public and private. This great miscellany includes graduation ceremonies, high-level deputations, installations of Chancellors, grand dinners, sermons by visiting preachers, ailments—major and minor—of himself and his relatives, wins and losses at whist, and jokes and puns heard in college common rooms. He records his various college and university duties: collecting fees, disciplinary procedures against erring students, and licencing the sale of alcohol in Cambridge's many public houses.[28] Joseph Romilly was politically a Whig, a good friend of Adam Sedgwick, and—despite their different political persuasions—an admirer of his Trinity colleague, William Whewell.

Romilly's accounts of the University's disciplinary procedures against errant students provide another view of student life. He officiated at the Vice-Chancellor's Court of Discipline, which had authority, in place of the civil

[27] Beverley (1833; 1834); Sedgwick (1836).

[28] In the last, he was assisted by one William Hunt, a fellow of King's college and a barrister, renowned as the most notorious drunkard in the University: Bury (1967), p.245.

courts, to deal with student crimes. Typical minor cases were a son of Lord Godolphin, Osborne of Magdalene "an ill conditioned unmanageable profligate", suspended for three terms for breaking lamps; four students suspended for two terms for being in a billiard room; and a student rusticated for one term, for being riotous and striking the police. Among more serious cases was an allegation that a Trinity student name Postle had drugged and then raped a girl, whose "Aunt (M^{rs} Whip) is a very bad woman & keeps a brothel. . . . Looks like a false acc^{n}:—else Postle has bought them off." Only the most serious cases went before the magistrates of the Cambridgeshire Court of Assizes: for instance, one of child cruelty involving a married student and his wife. Though gambling, like playing billiards and visiting brothels, was officially prohibited among the students, the regulations were enforced only in extreme cases. Thus, in February 1834, two Trinity students were expelled for gambling when one won a huge sum of nearly £800 from the other, who was unable to pay.

Less serious misdemeanors were often dealt with by the individual colleges. For example, a drunken student riot at Trinity College by two Lords of the realm and ten of their friends resulted in destruction of lamps and part of a balustrade in Nevile's Court: this was dealt with fairly leniently by the College Seniority (i.e. the Master and eight most senior Fellows or their deputies, a group that normally included Romilly), who confined the offenders to the "Gates and Walls" of the College for a time.

In February 1837, Romilly described "a most tedious case of discipline" following a breach of the peace by four Trinity men. Contrary to the accepted custom of returning the culprits to their college to be dealt with, the police took them to the police station and bail was demanded. The Vice-Chancellor, upset by this "gross violation of the Privileges of the Univ^{y}", instructed the students not to pay the bail money. Shortly afterwards, the town magistrates disputed the University's right to licence ale houses, and Romilly was required to provide the evidence of authority. These are just two instances of the often difficult relations between town and gown.[29]

[29] Bury (1967); above quotations from pp.74, 117, 16, 29, 48, 115.

3.
Cambridge University in Context

Parliament and the People

The 1830s were a politically turbulent time. Governmental power oscillated between the Whigs and Tories, and radical groups were increasingly vigorous and vociferous. In the aftermath of the Napoleonic Wars, the wages of the working class had decreased whereas taxes and the price of food had increased to meet the huge financial deficit.

It is incorrect to think of the Tories, on the one hand, as the party of the aristocracy and wealthy landowners; and of the Whigs, on the other, as the party of the meritocracy, intent on reforming out-dated practices and vested interests. In fact, Earl Grey's Whig cabinet of 1830 was composed entirely of aristocrats.[30] Leading Tories were Lord Wellington, Viscount Palmerston and Sir Robert Peel (the younger); and prominent Whigs were Earl Grey, Lord John Russell, Lord Henry Brougham and Viscount Melbourne. All just mentioned, except the brilliant but unpredictable Brougham, served periods as Prime Minister. Though some Whigs were keen reformers, many were reluctant to associate with more extreme radicals who shared some of their opinions. Only later, from 1847 and under the leadership of W.E. Gladstone, did the whole Whig party become identified with Liberalism.

During the 1820s, when the Tories were in power, the high import tariffs on many products were reduced in an effort to boost the flagging economy. Also, the Catholic Emancipation Bill was passed in 1829, allowing election of Roman Catholics to Parliament, though not admission to the English universities. In 1831, Earl Grey's Whig government proposed the first Reform Bill for redrawing constituency boundaries, extending suffrage, and abolishing

---

30 According to Woodward (1962), p.72: "all of its members except four were in the house of Lords, and, of these four, Althorp was heir to an English earldom, Palmerston was an Irish peer, Graham an English baronet with large estates, and Grant a Scottish landowner who was later raised to the peerage."

"pocket boroughs" which were effectively in the gift of local landlords. The bill was attacked by the Tories and failed. A general election resulted in a larger majority for the reformers, and the second Reform Bill was passed by the Commons but rejected by the Tory-dominated House of Lords. The votes of the Anglican bishops (all educated at Oxford or Cambridge) had been crucial, with twenty-one of them voting against the bill.

Following much public unrest, a third Reform Bill was introduced, and was again obstructed by the Lords, even though the King, William IV, had created a dozen new peers to support it. Earl Grey and his government resigned, but a new Tory government under Wellington proved unacceptable, and Grey was recalled by the King. Finally, on 4 June 1832, the house of Lords gave the bill its third reading and it became law.

In Cambridge, as elsewhere, the fate of the Reform Bill was followed with great interest, and opinion was divided. The University, like that at Oxford, elected two members of Parliament until 1887, when they were reduced to one each. One of the Cambridge M.P.s was William Cavendish (2nd, 1829), a Whig elected just a few months after obtaining his B.A.; but his support for the Reform Bill cost him his seat in the election of 1831. And Henry Goulburn was a Tory University M.P. from 1832 to 1856. A few days after the Reform Bill became law, Joseph Romilly dined with a party that included William Hopkins and his wife, at which "Clark and Hopkins preached over their wine about the reform bill"; then Romilly moved on to another grand dinner in his Trinity rooms in honour of the passing of the bill.[31]

Though the Reform Bill succeeded in placating public opinion, the number of eligible voters was increased only by about 50% to around 650,000.[32] The new middle-class voters brought little change to the composition of Parliament, and the working classes were still denied the vote by eligibility rules based on property value. Other reforms brought more significant changes to society. The 1833 Abolition of Slavery Act (with substantial compensation for slave owners) completed the process begun in 1807 by abolition of the slave

[31] William Cavendish later became seventh Duke of Devonshire and Chancellor of Cambridge University. Henry Goulburn was Chancellor of the Exchequer under Wellington in 1828–30, and briefly Home Secretary under Peel in 1834–35. Joseph Romilly mentions meeting Goulburn in November 1832; and he records that buying votes was still common in some places, his cousin John Romilly having lost by seven votes at Bridport in face of the "most shameful bribery". Goulburn's son, also called Henry and one of Hopkins' pupils, was admitted to Trinity College in 1830. Bury (1967), pp.16, 23, 66, 67.

[32] However, in Scotland it was increased from under 4500 to more than 60,000: Smith & Wise (1989), p.30.

trade. The Factory Act of the same year improved deplorable working conditions. The municipal corporations of England and Wales were reformed in 1835, and a form of self-government was granted to Canada in 1837. The first metropolitan police force ("the Peelers") had been introduced to London in 1829 by Robert Peel and was being copied by other cities; and the rapidly growing railway network revolutionised transport and facilitated the "penny post" mail service that began in 1840. Soon, Parliament would turn its attention to the old English universities.

Parliament, the Church and the Universities

Oxford and Cambridge degrees were awarded only to those who conformed, at least nominally, to the Thirty-Nine Articles of faith of the Church of England, and the colleges exerted extensive ecclesiastical patronage on behalf of their young graduates. Almost all Anglican priests with parishes in England and Wales were graduates of one or other university, since the various colleges had many parishes in their gift. Gonville & Caius College alone had nineteen Anglican Church livings in its gift in the mid-nineteenth century. Fellowships and Church livings of each college were reserved for the college's own graduates, and most were restricted to candidates with homes in specified English counties.[33]

At Oxford, students had to subscribe to the Thirty-Nine Articles on matriculation (i.e. when entering the university). Cambridge was somewhat more lenient, admitting nonconformists to study, but debarring them from scholarships, graduation and fellowships. Though many Scottish and Irish Episcopalians and some Presbyterians studied at Cambridge, Roman Catholics and most dissenting Protestants, such as Methodists, Unitarians and Quakers, were usually excluded or chose not to apply. Surprisingly, the brilliant Jewish mathematician J.J. Sylvester was admitted, but he had to leave without a degree, though listed as second wrangler in 1837.[34] Augustus De Morgan (4th, 1827), a nonconformist, was another eminent mathematician who could not

[33] Venn (1898), v.3, pp.311–322. However, Anglican priests who ministered overseas in the colonies were often without Oxford or Cambridge connections, and they were usually not licenced to preach in England.

[34] Sylvester was awarded B.A. and M.A. degrees from Trinity College, Dublin in 1841, without studying there, because of his Cambridge achievement. He eventually obtained his Cambridge B.A. and M.A. in 1872, when the rules were changed; and he later received honorary degrees from both Oxford and Cambridge.

graduate. Some colleges were more rigid than others: small numbers of Catholics and Jews, a Mohammedan and a Hindu were admitted, some but not all of whom got exemption from chapel attendance.[35]

Each Cambridge college had its own chapel for daily religious worship, and nearly all still do so today. Students were expected to attend both morning and evening services, and many voluntarily attended other churches in the town as well. Some, however, were upset when the Master of Trinity, Christopher Wordsworth, attempted in 1838 to increase compulsory chapel attendance from six to eight times per week: in protest, they formed a "Society for the Prevention of Cruelty to Undergraduates", and the measure was withdrawn.[36]

It was a religious age, and the Anglican Church was facing new challenges as it adapted to changing circumstances in a rapidly developing society. There were fresh moral and theological issues to confront. Industrialisation brought hardship and misery as well as prosperity. Foreign missions existed alongside harsh colonial exploitation. And recent discoveries of science were forcing

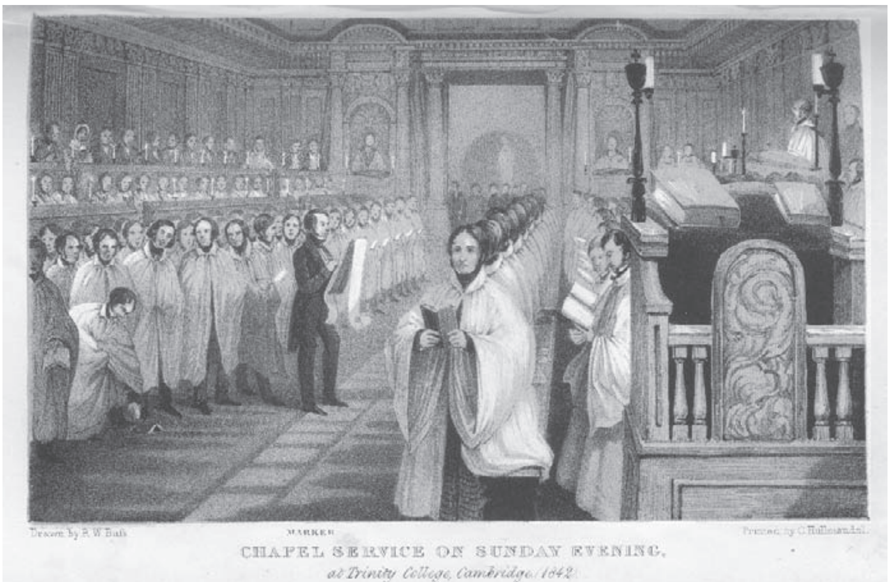


Figure 2. Chapel service on Sunday evening, Trinity College. Note the "marker" recording attendance. [Engraved drawing by R.W. Buss, from Huber (1843), v.2, facing p.316.]

[35] Winstanley (1940), p.83n.

[36] Smith & Stray (2003), p.5; Winstanley (1940), pp.390–393.

contentious and radical reinterpretations of the Bible, which could no longer reasonably be regarded as expressing literal truth. These burning issues were expounded from the pulpits of Cambridge's churches, where eminent visiting preachers drew large congregations.

Many students considered training for the priesthood after graduation: it was both a noble calling and a guarantee of a modest income. During 1820–40, approximately three-quarters of all Cambridge graduates became Anglican clergymen, schoolmasters or missionaries.[37] Until the 1870s, many college fellows were required to become priests if they wished to hold their fellowships for more than a few years.

Though Cambridge produced many celebrated scholars during the seventeenth century, its list of luminaries is far less impressive in the eighteenth.[38] According to one writer, "the University settled down to its eighteenth-century privacy, unmolested by Parliament, hardly interfered with by royalty, free to pursue its academic, pluralistic, slothful, learned, quarrelsome, bibulous, self-contained and supremely self-satisfied way."[39] But such indolent tranquility was disturbed in the early nineteenth century, the so-called "Age of Reform".

There was growing public concern about the privileges of, access to, and education at, the two ancient English universities. Calls for reform in the Whig and Liberal journals of Edinburgh and London reflected the opinions of the educational reformers Henry Brougham and Lord John Russell. Though themselves aristocrats, both the latter were strong advocates of wider educational opportunities for the middle and working classes. Significantly, they were educated at Edinburgh University, not Oxford or Cambridge: and, while there, Russell lodged in the house of none other than Professor John Playfair, one of the earliest critics of education at Cambridge and Oxford.

Support for reform was also growing in Cambridge itself. In 1834 Joseph Romilly signed a petition to Parliament to emancipate Cambridge degrees (except those in Divinity) from religious tests. Sixty-two resident members of Senate signed this petition to the House of Lords; but soon after, 110 members sent a rival protest against it.[40] The students, too, had their petitions, and it is interesting that they were more reactionary than the Senate: Archibald Smith reported to his sister that "there are about 1100 resident Bachelors and Undergraduates of whom 809 signed the petition

---

[37] Searby (1997), pp.741–743.

[38] The best of the mathematicians was Edward Waring, Lucasian professor during 1760–98.

[39] Steegman (1954), pp.31, 32.

[40] Bury (1967), pp.52, 53.

against—I was one of a small minority who signed the other."[41] The Church of England of course opposed the move, and it predictably failed. During the rumbustious debate in Parliament, Lord Palmerstone asked whether, in the interests of religion or the University, it was "either essential or expedient that young men should be compelled to rush from their beds every morning to prayers, unwashed, unshaved and half-dressed; or in the evening from their wine to chapel, and from chapel back again to their wine?"; but W.E. Gladstone refused to believe—either innocently or disingenuously—that collegians "even in their most convivial moments . . . were unfit to enter the House of Prayer."[42]

Other attempts followed, culminating in the 1850 Royal Commission discussed in Chapter 4. Though religious tests for students taking the B.A. degree were at last abolished in 1856, the tests remained for fellows at most colleges until the Test Act of 1871, and heads of colleges (who had to be ordained priests) still remained exempt. In 1860 and 1861, the two senior wranglers, Stirling and Aldis of Trinity, were debarred from fellowships because of these tests. And, as late as 1882, Selwyn College was controversially founded in accordance with strict Anglican principles.[43]

Unlike the secular London University (later University College London), which began in 1828, St David's College Lampeter, King's College London and Durham University were steadfastly Anglican foundations modelled on Oxford and Cambridge. The three last admitted their first students in 1827, 1831 and 1833 respectively, and Lampeter was created expressly to train priests for the Anglican Church in Wales. In contrast, the five ancient Scottish universities (St Andrews, Edinburgh, Glasgow and the later-amalgamated Marischal and King's Colleges in Aberdeen) were public institutions, partly funded by Parliament: they imposed no religious restrictions on their students, although they required professors to swear an oath to uphold the teachings of the Church of Scotland. In Ireland, Trinity College, Dublin (founded in 1581) was an Anglican institution with strong Cambridge connections: though it did not rigidly exclude Catholic students from attending, few did so. But

---

[41] Smith & Wise (1989), p.61, quoting Smith (ms.1834).

[42] Winstanley (1940), p.91, quoting *Hansard*.

[43] Further details on the religious tests are given in Winstanley (1947, Ch.3 and p.39). Selwyn was the first new college to be founded since Downing in 1800, apart from the short-lived Cavendish College, 1876–91. It was endowed by subscription in memory of George Selwyn, Bishop of Lichfield and formerly of New Zealand, the brother of William Selwyn, Lady Margaret Professor of Divinity (and sixth wrangler of 1828).

the three Queen's Colleges in Belfast, Cork and Galway (founded in 1845) were non-denominational, admitting both Catholics and Protestants from 1849. The first English higher educational institutions for women were Queen's College (1848) and Bedford College (1849) in London.

Even earlier than Cambridge, the Scottish universities had been the subject of a Royal Commission, set up by the Tories in 1826. It eventually reported in 1831, by which time the Whigs were in power. The Scottish universities' financial and administrative problems were obvious. An uneasy balance of power existed between the professoriate, town councils, and the Church of Scotland, not to mention factions within each of these groups. But the universities were surprised that the Commissioners also criticised the very nature of the broad general Scottish education, and advocated more specialised and narrower instruction closer to that of the two English universities. In particular, they recommended that less time be spent on moral philosophy and logic, in favour of Latin and Greek language and literature and more advanced mathematics. This was an attack on what were seen as traditional Scottish virtues, and the usually divided factions united in opposition. Churchmen, professors, town councillors, and Scottish peers all lobbied against the Report, which was finally withdrawn in 1836.

Between 1838 and 1858, new Commissions reported on each of the Scottish universities in turn, and there was a General Report in 1858. Support for reform of both the administration and the curriculum was growing, and in 1858 an Act of Parliament was at last passed. Further reforms were effected by another Royal Commission in 1876 and an Act of Parliament of 1889.[44] But, over this period, the standing of the Scottish universities declined while Cambridge underwent a remarkable revival.

In the 1830s and 1840s, Cambridge and Oxford were widely criticised for the same narrow specialisation that had been proposed by the Commissioners who examined the Scottish universities. As well as the over-narrow range of subjects that could be taken for a degree, criticism focused on the costliness of fees, Anglican exclusivity, the freehold privileges of college fellows and their (supposedly) enforced celibacy, and the great wealth of some colleges not put to good educational use. In contrast, the Scottish universities were much cheaper for students to attend, and imposed no religious tests on them; and they had few near-sinecures like those of fellows at Oxford and Cambridge. In his excellent general history of Cambridge University between 1750 and 1870, Peter Searby observes that:

---

44 Davie (1961); Anderson (1983).

> So much of the criticism of Oxford and Cambridge originated in Edinburgh that it might almost be called a campaign for Caledonianising the English universities: and this is ironic, since at the same time there was a struggle in Scotland to anglicise its universities by importing specialised honours degrees that were the best feature of the southern institutions. One might sum up by saying that Cambridge was Caledonianised rather less than Edinburgh was anglicised.[45]

One of the most cogent defences of the *status quo* in Cambridge came from the German writer, V.A. Huber in his 1843 account of *The English Universities*. He dismisses the cries for university reform as absurdly exaggerated and not based on deep insights, and he insists that the university is successful in its prime objective of educating *Gentlemen*, who are "a necessary and honourable element in the national existence":

> although it may be impossible to deny that the Universities neglect, more or less, or even entirely . . . a great many branches of learning which . . . daily increase in value and extent; it by no means becomes a duty to them to take these studies into their course to the *extent* and in the *manner* that their adversaries require. They may very justly reply:—"Our known and recognised duty and vocation was, up to the present time, not to form Divines, Jurists, Physicians, Chemists, Mechanicians, Political Economists, but to form GENTLEMEN, and next, SCHOOLMASTERS who may educate the rising generation of Gentlemen. . . ."[46]

It had not been demonstrated that this objective was less praiseworthy or necessary than those of the universities' critics.

However small the Scottish influence may then have been on undergraduate studies at Cambridge, it was Scotland rather than Oxford and Cambridge that provided the model for the new London University. Although Oxford and Cambridge were closely identified with Toryism, the aristocracy and the Anglican Church, many well-educated Scots were Whigs, Liberals or Radicals in politics and Presbyterians by religion. They were natural allies of English religious dissenters who opposed the Anglican dominance of their universities.

J.M.F. Wright's already-mentioned criticisms of the London University project drew attention to the involvement of Scots and Radicals in this venture.

---

[45] Searby (1997), pp.4, 5.

[46] Huber (1843), v.2, p.381.

Henry Brougham was one such supporter, who envisaged making higher education available to many who were debarred by poverty or religious belief. Among others who supported the project were the Glaswegian Thomas Campbell,[47] a popular poet, and the Quaker educationist George Birkbeck. Despite Wright's assertion, Birkbeck was born in Yorkshire and not Scotland; but he worked for a time in Glasgow, where his lectures to working men led to the foundation in 1821 of one of the first Mechanics Institutes. In 1823, he founded a similar Institute in London, which eventually became part of the University of London as Birkbeck College. As well as Brougham, Campbell and Birkbeck, other early supporters included the future Prime Minister, Lord John Russell, and the writer Thomas Babington Macaulay (later Lord Macaulay).[48]

The non-sectarian London University, supported by popular subscription, was at last founded in 1827 and it opened in 1828. But Oxford and Cambridge Universities joined forces with the Anglican Church in opposing the granting of a charter to the "godless" institution, whereas the Church-sponsored King's College, London, was immediately granted its charter in 1829. In a rather messy compromise, the Government founded the University of London in 1836, a nebulous body with powers to oversee the examinations of both University College (as the original London University was renamed) and King's College, and with authority to confer degrees. At the same time, Durham was forced to admit dissenters and grant them certificates, but not degrees; and London was compelled to recognise these certificates for *its* degrees. The sole function of the University of London as an examining and degree-awarding body was soon extended to embrace other affiliated colleges and medical schools, including Owens' College in Manchester and even the far-distant University of Malta and Ceylon Military Hospital.[49]

Promoting Education and Science

Henry Brougham (later Baron Brougham & Vaux), was a lawyer, amateur mathematician, and journalist before entering politics. In 1820, he received much public notice by representing Queen Caroline against King George IV's disgraceful attempt to divorce her. He became Lord Chancellor in the Whig

---

[47] He wrote *The Pleasures of Hope* and other works, and should not to be confused with two other poets of the same name.

[48] Woodward (1962), pp.491, 492.

[49] Cardwell (1972), pp.46–49, 92.

governments led by Earl Grey (1830–34) and Lord Melbourne (1834), when he oversaw various educational and legal reforms.

Brougham was instrumental in founding the Society for Diffusion of Useful Knowledge, which published cheap, self-help texts on a wide range of subjects. This society was a secular rival to the long-established Society for the Propagation of Christian Knowledge. Brougham was its first chairman and Lord John Russell its vice-chairman. Each volume proclaimed an impressive list of names on the large Committee, many of them also supporters of London University. A number were fellows or professors of Cambridge University, who wished to reform their own institution. Among these were John Henslow, Adam Sedgwick, George Peacock and Connop Thirlwall, who feature later in this account.

Though the authors of the Society's texts were not always named, it is known that Brougham himself wrote several sections.[50] Other mathematical and scientific authors include Augustus De Morgan, Samuel Wilkes Waud, William Hopkins, Dionysius Lardner and David Brewster. But the entrepreneurial Irishman Lardner also edited the rival *Cabinet Cyclopaedia*, a multi-volume publication commended by the *Edinburgh Review*:

> Of the many works which have been lately published in imitation, or apparent imitation, of the plan adopted by the Society for Diffusion of Useful Knowledge, Dr. Lardner's Cyclopaedia is by much the most valuable, and the most recommended by distinguished assistance, scientific and literary.[51]

As well as these texts aimed at self-improvement, there were several large encyclopaedia projects. The *Encyclopaedia Britannica* was first in the field, and was regularly updated with new editions and supplements. In our period, these were edited by Macvey Napier of Edinburgh. David Brewster's *Edinburgh Encyclopaedia* and the London-based *Encyclopaedia Metropolitana* and *Rees' Cyclopaedia* were its most serious rivals. All attracted writers of high calibre, and many scientific and mathematical articles were genuinely up-to-the-minute surveys. For example, around 1820, the Scots

[50] The writer's copy of the volume *Natural Philosophy I* (1829) has the author of each chapter identified in pencil in an old hand: the *Preliminary Treatise: Objects, Advantages, and Pleasures of Science* and the fifth chapter on *Hydrostatics* are attributed to Brougham.

[51] From an advertisement sheet in Lardner (1829–39), quoting the *Edinburgh Review*, Oct. 1830.

mathematician James Ivory published articles on "Equations" and "Attraction" (due to the Earth's combined gravitation and rotation) in the *Encyclopaedia Britannica Supplement*: these not only described recent French and German discoveries, but incorporated some of Ivory's own original work. Similarly, William Wallace, Ivory's colleague at the Royal Military College, wrote for both the *Edinburgh Encyclopaedia* and the *Encyclopaedia Britannica*.

The Cambridge-educated John Herschel contributed a major article "Mathematics" to the *Edinburgh Encyclopaedia* as well as writing for the *Encyclopaedia Metropolitana* and later for the *Encyclopaedia Britannica.* Herschel's Cambridge contemporaries, Charles Babbage, Edward ffrench Bromhead and George Peacock (of whom more later) also wrote for one or other of the Edinburgh-based encyclopaedias. But few other Cambridge-based scholars did so. Typical was the rebuff sent by Robert Woodhouse in reply to an invitation from Macvey Napier:

> I ought earlier to have acknowledged your letter, which, together with one from Prof^{r}. Playfair I received on Monday last. My tardiness, however, has not originated from hesitation; for it does not suit my Inclination and plans to engage in an undertaking such as you have spoken to me of . . .[52]

Educating the working classes was not a high priority at Cambridge: those who published at all mainly wrote textbooks for their own undergraduates. Exceptions were S.W. Waud (5th, 1825), a fellow of Magdalene College, and William Hopkins: Waud's substantial *A Treatise on Algebraic Geometry* and Hopkins' shorter *Trigonometry* were both published in 1835 in the "Library of Useful Knowledge" series.

Elsewhere, however, major efforts were being made to extend practical education. The Royal Institution of London, founded in 1799, held regular lecture series, and employed the great experimental scientists Humphry Davy and Michael Faraday. The Mechanics Institutes of Glasgow (founded in 1821) and of London (1823) owed much to George Birkbeck, and the Mechanics Institute movement rapidly spread to other manufacturing cities. The Royal Scottish Society of Arts in Edinburgh was begun by David Brewster in 1821 as a meeting place for engineers, tradesmen, craftsmen and artisans in the "useful arts" of science, technology, engineering and manufacture. Its model was London's Society for the Encouragement of Arts, Manufactures and

---

[52] Woodhouse (ms.1814).

Commerce, which had existed since 1754 and is now the Royal Society of Arts. The Edinburgh School of Arts also opened in 1821, offering courses in chemistry, natural philosophy, mechanics and their applications. (This later became Heriot-Watt College and then Heriot-Watt University.) Anderson's College in Glasgow started even earlier, in 1796, after a bequest from John Anderson, Professor of Natural Philosophy at Glasgow University, to found a "place of useful learning", open to everyone regardless of gender or class. By the mid-nineteenth century, it had a high reputation for technological instruction, suited to the burgeoning manufacturing and shipbuilding industries of the city. (After some amalgamations, this college became Strathclyde University in 1964.) In Ireland, the non-sectarian Belfast Academical Institution began in 1814, part school and part college: James Thomson (father of William Thomson) was its professor of mathematics until he moved to Glasgow University in 1832.

In London, the Royal College of Chemistry was founded in 1845, and the Government School of Mines and Science Applied to the Arts was founded in 1851: the two merged in 1853, and further mergers led, in 1907, to the creation of the Imperial College of Science and Technology. Owens' College in Manchester also began in 1851, funded by a gift from the textile-merchant John Owens: in 1900, this became the Victoria University of Manchester. But, long before Owens' College's foundation, Manchester had an active scientific culture: its Literary and Philosophical Society began in 1781; there followed a Natural History Society in 1821, Mechanics Institutions in 1825 and 1829, and a Geological Society in 1838. Earlier Manchester colleges, from the 1780s onwards, had brief lives. One of these, the Dissenters' New College, for a time employed the chemistry pioneer John Dalton to teach science and mathematics. Some other cities, too, had their colleges; and many had Literary and Philosophical Societies, which did much to foster the intellectual aspirations of their citizens. At a more mundane level, many towns and cities hosted itinerant lecture demonstrations of popular science, illustrating the wonders of astronomy, physics and chemistry.[53]

Unlike Cambridge University, the city colleges and mechanics institutes emphasised practical science. The outlook of northern-based scientists such as John Dalton, James Joule and David Brewster had far more in common with that of the great engineers of their day than with the attitudes of fellows and professors at the old English universities. They were interested in the applications of science, not just in science *per se*. Using and often inventing the latest technology, the engineers Thomas Telford, John and George Rennie

---

53 Kargon (1977); Cardwell (1972).

constructed bridges, canals, roads and harbours; George and Robert Stephenson made railway locomotives and railroads; John Scott Russell designed and built ships; Isambard Kingdom Brunel built tunnels, bridges, railroads and iron-hulled steamships; and George and Thomas Stevenson built lighthouses. Not one of those engineers studied at Oxford or Cambridge, but several were students in Scotland.

Also providing practical instruction were the various military colleges. The foremost were the Royal Military Academy, Woolwich; the Royal Military College at Marlow, later Sandhurst; the Royal Naval Colleges at Greenwich and at Portsmouth; the Scottish Naval and Military Academy, Edinburgh; and the Honourable East India Company College, Haileybury. These all had professors or lecturers in mathematics, some of whom were notable scholars: among them were James Ivory, William Wallace, Charles Hutton and Olinthus Gregory.

The British Association for the Advancement of Science was founded in 1831, largely through the initiative of the Scots David Brewster, Sir John Robison and James D. Forbes. They received the ready cooperation of W. Vernon Harcourt and John Phillips of York to hold the first meeting in that city. Though the professoriate of Oxford and Cambridge were suspicious of the new body, and none attended its inaugural meeting, William Whewell, then Cambridge's Professor of Mineralogy, wrote urging the Association to commission "reports . . . concerning the present state of science, drawn up by competent persons". The second meeting of the Association was held in Oxford, and this time it was attended by many of Cambridge's best scientists.[54] The third meeting was held in Cambridge in 1833, with Adam Sedgwick as President, and the meetings in 1834 and 1835 were held in Edinburgh and Dublin respectively.

A valuable feature of these meetings was the commissioned reports first proposed by Whewell, that were published as part of the annual proceedings. By the late 1830s, the Association was rich enough to offer grants to support experimental researches for these reports. Among their most successful commissions were the reports on water waves by John Scott Russell and Sir John Robison: these experimental studies led others to make fundamental theoretical advances on fluid motion.[55] The national character and high esteem of the Association were quickly established, and its annual meetings continue

[54] Howarth (1931), Ch.1. The diplomatic Harcourt ensured Cambridge participation by arranging that *both* Brewster and Whewell, who were great rivals, became vice-presidents.

[55] Russell & Robison (1837); Russell (1844).

to this day (though now with less influence). As the first regular national forum accessible to all scholars, it had a crucial role in encouraging scientific research, in disseminating recent discoveries, and, to some extent, in breaking down artificial barriers of clannishness and institutional rivalry.

Until the establishment of the British Association, the only national bodies devoted to science in general were the socially exclusive Royal Societies of London and Edinburgh and the Royal Irish Academy. These latter bodies had catered more for the dilettante tastes of gentlemen amateurs than for the needs of scientific research. But from around 1825 the Royal Society of London began to restrict membership to those with demonstrable scientific interests, and several more-specialised scholarly societies came to prominence. The Linnean Society for biology had begun in 1788, the Geological Society of London (later the Royal Geological Society) was founded in 1807 and the Royal Geographical Society in 1830. The Astronomical Society of London was founded in 1820 by a group dissatisfied with the running of the Royal Society, and it was incorporated as the Royal Astronomical Society in 1831. The present magnificent premises of the British Museum took shape during 1828–51. The Geological Societies of Scotland and of Ireland were established in the early 1830s, and the Statistical Society of London (later the Royal Statistical Society) in 1834. The very early Spitalfields Mathematical Society, founded in 1717, had lost much of its vitality by the 1820s, but it remained in existence until 1845. The Meteorological Society of London was founded in 1823: it soon closed, but was revived in 1836. In 1850, it became the British Meteorological Society (and, in 1883, the Royal Meteorological Society).

All these societies published Transactions or Proceedings containing scientific papers read at their meetings. So too did the purely Cambridge-based Cambridge Philosophical Society, which was founded in 1819 on the initiative of Adam Sedgwick and John Henslow. Other journals were aimed at a wider public and the commercial market: those published in London were Alexander Tilloch's *Philosophical Magazine*, William Nicholson's *Journal of Natural Philosophy, Chemistry and the Arts*, and the *Annals of Philosophy*; and in Scotland there were the *Edinburgh Journal of Science* and the *Edinburgh Philosophical Journal.* These all published book reviews, short original articles, and often vituperative correspondence on a wide range of scientific topics.

There was no British journal wholly devoted to mathematics and its applications apart from *Dodson's* (later *Leybourn's*) *Mathematical Repository*, based at the Royal Military College, Marlow, and its short-lived successor *The Mathematician*, based at the Royal Military Academy, Woolwich. These published little original work, but a mix of summaries and translations of British, French and German articles that had appeared in the journals of scholarly societies, and monthly problems for readers to tackle, with the previous month's solutions: yet they provided a useful service for a disparate readership. Also popular, and far from trivial, were the mathematical problems that were part of the miscellanies of *The Ladies' Diary* and *The Gentleman's Diary* (which amalgamated in 1841). But the first British mathematical journal to build a reputation in research was the *Cambridge Mathematical Journal* (later the *Cambridge and Dublin Mathematical Journal*) that began in 1837: more is said about it later, for several of our wranglers were involved. The influential London Mathematical Society was not founded until 1865, and the Edinburgh Mathematical Society followed in 1883. In the late 1860s, the Association for the Improvement of Geometrical Teaching (later The Mathematical Association) was founded for school-teachers, and published *The Mathematical Gazette*.

The Town and University of Cambridge

The population of Cambridge in 1832 was just 21,000 inhabitants, and this increased only slightly to 24,453 (including students) in 1841. The number of resident members of the University at this time amounted to about two thousand. Apart from the University and the services that it generated, there was little business apart from trade of coal and corn, and the transport to London, via the river Cam and by wagon, of locally produced butter and flax-seed oil. A contemporary Guide Book described the town as "certainly below what might be expected", with streets "narrow and winding, and the houses . . . in many instances old, ill-built, and crowded closely together"; but it mentions a "general spirit of improvement" with the building of a "number of houses of a better and more genteel description".[56] Nevertheless, whatever the town's other deficiencies, it possessed several attractive small parish churches, some predating the foundation of the university: St Benet's has a Saxon tower from about 1050, and the Norman "round church" of the Holy Sepulchre dates from around 1130.

In contrast, the colleges of the University include some of the most imposing, and some of the most beautiful, buildings in Britain, from many different periods and in many different styles. The earliest, St Peter's College (now known as Peterhouse), was founded in 1284, but long-vanished residential hostels associated with religious orders date back even further, to the early years of that century. Five colleges founded in the fourteenth century still

[56] Quoted in Bury (1967), p.x.

survive: Clare (1326), Pembroke (1347), Gonville (1348: now Gonville & Caius and commonly abbreviated to Caius), Trinity Hall (1350), and Corpus Christi (1352). King's College followed in 1441 and Queens' in 1448—both royal foundations. Then came St Catharine's (1473), Jesus (1496), Christ's (1505), St John's (1511), and Magdalene (1519). Though all were threatened in 1545 by an "Act for Dissolution of Collegiate Foundations", they managed to survive intact; and Henry VIII, probably persuaded by his Queen Catherine Parr, soon afterwards founded Trinity College in 1546, incorporating several earlier foundations. In 1557, John Caius, the country's leading medical scientist, obtained permission to remodel his old college, Gonville, which now bears both names. Next, under Puritan influence, Emmanuel College was founded in 1584. In 1591, Cambridge was involved in setting up and staffing Trinity College in Dublin; and Sidney Sussex College was established in 1596. This was the last college to be founded until Downing in 1800. [See Plates 2–5, Chapter 6, from Ackermann (1815).]

These were the seventeen Cambridge colleges in existence at the time covered by the present work, but more were added later. The standing of Downing College remained low throughout the nineteenth century; and the foundation of Selwyn College in 1882, expressly to provide a "Christian training, based upon the principles of the Church of England", offended many liberals who had fought for and won the Universities Religious Tests Act of 1871. Even more controversial were the first women's colleges, Girton (1869) and Newnham (1871). Though tolerated, their members were not given full University status until the late date of 1947, and no female student is recorded in Venn's *Alumni*.[57]

In the early decades of the nineteenth century, the University expanded considerably. There were several new, lavish, college building projects, and the numbers of graduates rapidly tripled. Indeed, many of today's best-known views of Cambridge did not come into being until this time. Around 1800, just over one hundred degrees were awarded annually. By 1825, this number had increased to more than 300, roughly one-third of them at honours level. The numbers then remained fairly static during the period of our study; but, between 1860 and 1890, there was a second dramatic increase, when the number of graduates increased to almost 800 per year.[58]

Relations between town and gown were often hostile. According to the Cambridge historian D.A. Winstanley, "The University was never reluctant to

[57] At the present time, there are thirty-one colleges, nearly all admitting students and fellows of both sexes.

[58] See e.g. Searby (1997), p.61; Venn (1898), v.3, p.392.

cause annoyance to the Town, and the Town was always on the lookout for an opportunity to humiliate the University." The Mayor and Borough Council quarreled with the University authorities over the University's disputed right to licence ale houses and arrest prostitutes, and the town's disputed right to arrest students for assault. As late as 1843, an Act of Parliament reinforced the Vice-Chancellor's right to licence or prohibit all theatrical and musical performances within fourteen miles of Cambridge. As a result, no plays and few concerts were performed in Cambridge except during the long vacation: the townspeople were deprived of entertainment "in order that undergraduates should not be distracted from their studies or run after actresses."[59]

Following the 1852 Report of the Royal Commissioners into the University, talks took place between the Borough Council and the University; and, when these broke down, an independent arbiter was appointed to resolve the remaining disputes. The University lost some of its rights, including that to licence ale houses and to supervise weights and measures; but it retained those to arrest and punish prostitutes, and to licence theatrical entertainments. Much, but not all, of the University and college property became liable for assessment for parochial rates; and the arbiter fixed the University's formerly *ad hoc* contributions to the Borough Council towards maintaining the police, and the paving, cleaning and lighting of the town's streets. Because neither side was an obvious winner or loser, relations thereafter became rather more amicable. Though difficulties continued to surface over the respective responsibilities of Borough and University, by 1890 it was possible for a University man to be chosen Mayor of Cambridge.[60]

Though Cambridge University could usually speak with one, usually reactionary, voice when threatened by external interference, its internal central administration was weak and its constituent colleges strong. The seventeen autonomous colleges each had its own head and its own fellows. These colleges varied greatly in size and wealth, much as they do today. By far the largest and wealthiest were (and are) Trinity, St John's and King's Colleges. The position of King's College was anomalous. In the words of Charles Bristed, the College was "a mere prolongation of Eton School. Its half-dozen Undergraduates, who have been the best 'Collegers' at Eton, become Scholars and Fellows of the College as a matter of course, and also get their degrees from the University without passing any examination for it."[61]

---

[59] Winstanley (1940), quotations from pp.122, 127.

[60] He was Frederick Charles Wace (3rd, 1858), a fellow of St John's in 1860–75 and Esquire Bedell during 1877–93. See also Winstanley (1940), pp.129–138; (1942), Ch.4.

[61] Bristed (1852), v.1, p.174.

The University Vice-Chancellor was elected from among the college heads to serve for only a year at a time (often reappointed for a second year), and his first loyalty remained to his college.[62] Chaired by the Vice-Chancellor, the heads comprised a committee for the selection of professors to fill vacant chairs, and for drafting new university regulations or "Graces" to be considered by the University Senate. The Senate was a very large body, consisting of all professors, fellows and graduates with M.A. or doctorate degrees: those resident in Cambridge numbered more than two hundred, and non-resident members could also attend.

But, before any Grace could even be put to the vote of Senate, this had first to be approved by the Caput, every member of which had a veto. Accordingly, the Caput was a powerful body, capable of blocking discussion in Senate if any member chose to use his veto. It consisted of the Vice-Chancellor and five others elected for one year, one from each of the faculties of divinity, law and medicine, and two from arts. The electorate for the Caput was itself a small one, consisting of the heads of colleges and a few others. Though such a system could easily be used to *stop* new proposals, it was ill-suited to *starting* them. R.M. Beverley's 1833 polemic put this more colourfully: "These five effete legislators have each an extinguisher for any spark of improvement that may be discovered in the rotten tinder of the university." As part of the 1850s reforms, the Caput was replaced in 1856 by a somewhat more democratically elected Council, which could veto a Grace only by a majority.[63]

With a weak central organisation, the colleges were free to act independently. Though each had a notionally democratic structure in which senior fellows participated, the head of the college wielded much power. At Trinity, for instance, the Council consisted of the Master and the eight most senior fellows; but R.M. Beverley maintained that every college was despotic, observing that the Master of Trinity had eight votes and each fellow just one, which meant that the Master needed just one supporter to be sure of a majority!

College politics and archaic college statutes produced some strange appointments. One of the strangest was that of Benedict Chapman as Master of Caius in 1839. Chapman, who held a college Church living in Essex, had been absent from Cambridge for twenty years. According to John Venn:

---

[62] The head of most colleges is called the Master, but at King's he is the Provost, and at Queens' the President.

[63] Winstanley (1940), pp.286, 287; Beverley (1833), p.4.

> Such an election—he was already in his seventieth year,—was not the result of those motives only which are commonly supposed to sway men in their choice of master. Indeed it is no secret that in the minds of several of the electors his merits lay, not so much in his personal character, as in the fact that by choosing him there was a prospect of another election within a few years; when Dr. Paget, who was at that time below the statutable age, would almost certainly be chosen.[64]

But the scheme misfired badly as Chapman lived on until 1852, by which time Paget had married and lost hope of the succession. Chapman's responses to the 1850 Royal Commission, discussed below, were among the most reluctant and reactionary.

College Life

The comforts and privileges of fellows, and the university's primary aim to produce well-educated vicars and gentlemen rather than scientifically learned or practically skilled men, have already been mentioned.[65] The lifestyle of fellows in the 1840s at the especially well-endowed Trinity College was described by Charles Bristed as follows:

> They have a handsome income, whether resident or not; but if resident, enjoy the additional advantages of a well-stocked table for nothing, and good rooms at a very low price. The only conditions of retaining their Fellowships are that they take [holy] orders after a certain time and remain unmarried. Of those who do not fill college offices, some occupy themselves with private pupils; others, who have property of their own, prefer to live a life of literary leisure, like some of their predecessors, the monks of old.[66]

At most of the colleges, younger fellows were not well paid, and many stayed for only a few years. But fellows also received, according to seniority, an annual dividend from the college income of rents on property: at some colleges, especially Trinity and St John's, this could be a substantial sum. Several of the younger fellows retained their fellowships and benefits while studying

---

64 Venn (1898), v.3, p.137.

65 See also Winstanley (1940; 1947); Rothblatt (1968); Garland (1980).

66 Bristed (1852), v.1, p.21.

for the Bar at the Inns of Court in London, and they sometimes acted as Moderators and Examiners for the Tripos while doing so.

Some of the long-term fellows treated their positions as sinecures and did little or nothing. One of the most notorious was Hamnett Holditch of Caius College, who was senior wrangler in 1822. In John Venn's opinion, Holditch "would probably have distinguished himself had he been compelled to work", but "beyond a few private pupils, never took part in educational work". Similarly, Christopher Brooke, in his more recent history of the college, states that Holditch "abandoned every temptation to work", despite holding successive paid College posts as lecturer in Hebrew and in Greek, registrar, steward and bursar. (Nevertheless, he did manage to produce ten mathematical papers, which is more than many holders of the Lucasian Chair could manage.) From 1835 until his death in 1867, Holditch was a virtually invisible President of the College, next in command under the Master, but spending most summers fishing in Scotland or Wales.[67] Given a system that tolerated and even rewarded such indolence, it is remarkable that so many fellows took their duties seriously and cared about the students in their care.

Inter-college rivalry focussed primarily on academic honours in the Tripos examinations. The spirit of competition was not confined to the student body. The fellows, too, got caught up in the excitement of the annual academic trial of strength. Betting was common: college servants, students and fellows alike backed their favourites for senior wrangler and top classics student. The results were widely reported in the national press and the senior wrangler was accorded celebrity status:

> A nationally reported ceremony of this kind played an important role in shaping both public perceptions of Cambridge University and the sensibilities of undergraduates towards their studies. The British public came to regard the study of mathematics as the pinnacle of intellectual achievement, and the term "senior wrangler" became synonymous with academic supremacy.[68]

Each year, Joseph Romilly faithfully recorded the success of the senior wrangler in the Tripos, and the conduct of the graduation ceremony, in terms that reveal the extent of this rivalry. Nowadays, it is hard to understand the pride that the winning college took in the success of one of its members, given that almost all candidates received their instruction from a private tutor

67 Venn (1898), v.2, p.170; Brooke (1985), pp.194, 195.

68 Warwick (2003), p.205.

frequently unconnected with the college. Yet rivalry, pride, and disappointment over defeated favourites there certainly were.

The following excerpts from Romilly's diary give the flavour:[69]

> Jan. 1833: Ellice of Caius is S[enio]^{r} W[rangle]^{r} & a very good one. . . . Much applause for Ellice who is popular as well as clever.
>
> Sept. 1833: Birks [of Trinity] (who is a great Math^{l} genius & is to be Sen^{r} W r[angler]) . . . Birks very shy.
>
> Jan. 1834: We are prodigiously mortified: our Champion Birks is beaten: Kelland of Queens is the Hero of the day.
>
> Jan. 1836: We [i.e. Trinity] have the senior Wrangler: his name Archib. Smith: he is a Scot & the 1st of his nation who has ever been S.W.—The 4th Wr^{r} is Aldam a Quaker.[70]
>
> Jan. 1837: St Johns has the first 3, viz. Griffin, Sylvester (a Jew!!!) & Brumell . . . Green of Caius (son of a miller) who was expected to be S.W. was only 4th.
>
> Jan. 1839: S^{t} Johns has gained an unpreced^{d} honor, the 4 first Wranglers . . . at Trinity we are much disgusted having nothing higher than 5th (Mathison): the great man of the Jesuits (Hearne) was only 6th:—general dissatisfaction against Bullock (the Johnian Math. Ex^{r}) who is thought to have been unfit for his duties . . . joke of the day was that Cowie was S.W. because Bullock had been Exam^{r}.
>
> Jan. 1841: Stokes of Pembroke S.W. & a very good one: the last Pemb. S.W. was Ainslie in 1781. . . . Declined dining at Pembr. at the grand dinner today in Pembr. Hall in honor of Stokes,—whom they have this day made Fellow.
>
> Jan. 1843: Adams of St John's is the Senior Wrangler.—Goodeve of St J would have been 2d (it was expected) but after 3 days he was seized with a panic terror and bolted:—in spite of this he is 9th Wrangler.
>
> Jan. 1846: Hurrah for Trinity, we have the Senior Wrangler (Hensley): he is the 2d from King's College [London]—Cayley having been the 1st.

[69] Bury (1967), pp.27, 38, 45, 96, 111, 162, 208; Bury & Pickles (1994), pp.41, 157; Bury & Pickles (2000), pp.98, 99, 430.

[70] Romilly is not quite right: Alexander Ellice, senior wrangler in 1833, was also born in Scotland, though he attended Harrow School before entering Cambridge.

> Jan. 1852: Peterhouse is covered in glory—they have the 1st 2 viz. Tait & Steele:—Steele was the favorite of Hopkins & was fully expected to beat Tait:—he is of course greatly disappointed:—the Johnian champion Godfray (a married man who had been a schoolmaster) is only 3d: he fainted away one day of the Examination.—The moment the Peterhousians heard of their glory they issued invitations for a grand dinner tomorrow and sent me a card.
>
> Jan, 1863: Routh (Peterhouse) was the private tutor of 9 out of the 1st 10 Wranglers including the Senior Wrangler: Routh seems to have taken the place of Hopkins as Senior Wrangler maker.

During 1827–60, St John's college had seventeen senior wranglers and Trinity only seven. Of the smaller colleges, Queens' and Peterhouse both had three, Caius two, and Pembroke and St Catharine's one each. Of these thirty-four senior wranglers, at least twenty studied for a time with William Hopkins. If St John's excelled in mathematics, Trinity outdid the rest in the Classical Tripos, with twenty-four Senior Classics out of thirty-three between 1824 and 1856: St John's was next with six, whereas Peterhouse, Pembroke and Corpus managed one each. The rivalry between the two largest colleges was particularly intense, and engendered a mutual hostility and social exclusivity. In Trinity, St John's men were pejoratively known as "Johnian pigs", and Joseph Romilly recorded the joke that a newly painted wall at St John's had acquired a new *pig*ment.[71]

One group that crossed college boundaries was the "Cambridge Apostles", a self-selected intellectual and social élite that held private debates and circulated essays among the membership. Its members obeyed a secretive code of solidarity and mutual support that extended well beyond their student days. But their numbers were dominated by Trinity men and by those who had attended prestigious public schools such as Eton and Harrow. Though their influence in literature and criticism was considerable, it was less so in mathematics and science. Despite the intellectual kudos attaching to top wranglers, only a few became members: in our period, D.D. Heath, J. Clerk Maxwell, H.W. Watson, G.V. Yool and H. Blackburn.[72]

[71] Bury (1967), pp.86, 227.

[72] Other members included James Stuart (3rd, 1866) and, later, the eminent scholars Alfred North Whitehead (4th, 1883), Bertrand Russell (7th, 1893), G.H. Hardy (4th, 1898) and John Maynard Keynes (12th, 1905): see Lubenow (1998). Later still, their numbers included the notorious Soviet spies, Guy Burgess, Donald Maclean and Anthony Blunt.

Though most of the Apostles had attended top public schools, this was not so of students generally at this time. A.H. Wratislaw, a tutor of Christ's College, complained of this in his *Observations on the Cambridge System* (Wratislaw 1850). Apart from Trinity, and Eton-dominated King's, Wratislaw asserted that the colleges recruited mainly from "commercial and other inferior or even professedly mathematical schools" whose pupils were "almost utterly devoid of the slightest pretence to a preparatory liberal education".[73] In all, Wratislaw estimated that no more than a third of Cambridge students came from the public schools, and that no more than a third of the boys educated at public schools went on to university.

As well as rivalry between colleges, there were inevitable intrigues and plots within individual colleges. Power struggles often centred on appointments, personal ambitions and animosities, but they sometimes reflected real political and educational differences as well.

One of the worst disputes at Trinity broke out when the Master, Christopher Wordsworth, insisted on dismissing Connop Thirlwall from his fellowship. Thirlwall was a Greek historian and an ordained priest who later became Anglican bishop of St David's in Pembrokeshire. In 1834, he publicly called for the admission of Dissenters as students, and for the removal of all religious teaching from the B.A. degree. The Tory Wordsworth, brother of the poet William Wordsworth, took precipitate action, only to discover that he did not have the support of the fellowship. Refusing to back down, he retreated into isolation, taking little further part in college business. Though he wished to retire, he did not want to facilitate the appointment of Adam Sedgwick or George Peacock, both noted Whigs, who were most likely to succeed him. Instead, he remained in post until Robert Peel's Tory government came to power in 1841, and then immediately resigned. Because the Mastership was a Crown appointment in the gift of the government, and the Tory William Whewell was now old enough to be eligible, it was Whewell, and not Sedgwick nor Peacock, who was appointed.[74]

There was less doubt about the propriety of the dismissal, on 8th November 1836, of one Cliff Hatch, a fellow at King's, who, in Romilly's words, was "deprived of his Fellowship for incontinence, he having a large illegitimate family: the charge brought forward by a blackguard Col. Wetherall (or some such name) . . . Hunt sent off his Mistress & has decamped himself. . . ." There was notional celibacy in the colleges, and, until the 1860s, fellows had to resign on marriage. It seems that Hatch was deprived of his fellowship not for immo-

[73] Also quoted in Winstanley (1940), pp.413, 414.

[74] Romilly's comment on this is in Bury (1967), p.220.

rality but for "being a married man according to the spirit of the College Statutes", and the complainant "Col. Wetherall" was deemed a blackguard for raising the matter![75] Yet, just a year after Hatch's dismissal, Caius College felt able to elect the talented mathematician George Green to a fellowship, turning a blind eye to the several illegitimate children he had left behind in Nottingham (see Chapter 8).

Joseph Romilly once lost "a Rump and 12" (a rump of beef and twelve bottles of claret, paid for by the loser at a dinner for the winners), betting on who would be awarded the Chancellor's medals for the two senior classics. Romilly also frequently gambled at whist, typically winning or losing several pounds, often to the mathematician (and future Dean of Ely Cathedral) George Peacock.[76] In the Combination Room of Caius College, the fellows maintained a wager book, which still survives: this records many bets of bottles of wine, purchased by the losers for common consumption.[77]

Solomon Atkinson aimed one of his sharpest barbs at "Mr K—g", tutor of Queens' College and former senior wrangler [Joshua King, later President of Queens' and then Lucasian Professor of Mathematics], who

> *might* have been one of the first mathematicians of Europe: he *is* the tutor of his college. His extraordinary powers . . . are wholly employed in making up college bills, arranging college squabbles, and looking after the morals of freshmen. His knowledge of mathematical science *was* most extensive, and his mastery over it complete. At present the game of whist is his foremost study, and probably he will end his career much more familiar with Hoyle than LaPlace. The man that might have rescued the name of English science from contempt is fast approaching the honours of a three-bottle man in a tippling college, and the best whist player in a gambling University.[78]

Such behaviour exemplifies the indulgent, often indolent, and sometimes disreputable nature of collegiate society, of which countless more examples could be cited.[79]

---

[75] Bury (1967), p.106. William Hunt, the fellow of King's here taking evasive action, is the same barrister and drunkard who assisted Romilly in licencing public houses.

[76] Following a meeting at the "Philosophical" in March 1833, Romilly recorded that "G.P. came in afterwards & played cards till horrid late." The following night too, "G.P. looked in & plund[ere]d me" (Bury 1967, pp.30, 31).

[77] Cannell (2001), pp.108–112.

[78] Atkinson (1825a), pp.503, 504.

[79] See, e.g. Winstanley (1947), Ch.16.

Ceremonial events were of course occasions for the most extravagant wining and dining, often described in detail by Joseph Romilly. Among his ceremonial duties, Romilly was responsible for issuing much-sought-after tickets for the events in July 1835 marking the first Commencement ceremony presided over by the new Chancellor, the Marquis Camden. The festivities included a grand dinner for more than four hundred at Trinity College, lavish even by the standards to which Trinity fellows were accustomed. A profusion of turtle, venison, light wines (but no champagne) was distributed by 280 servants. But for Romilly it was not a joyful occasion, on account of the "insufferably tedious . . . speeches of our Master" and the replies by three dukes and the Archbishop of Canterbury, the last of whom was particularly unbearable. The very next day, a similar event took place at St John's College, where "there was a profusion of Turtle (unfortunately burnt), Venison, Champagne, &c: & the dessert in part^{r} was the most abundant & sumptuous I ever saw set on a Table." Dancing followed in a marquee at Downing College and at a Charity Ball in the Town Hall.[80]

Towards a Modern University

From the 1850s, there was a growing emphasis on physical exercise among the students. Long hikes, rowing, team games—and also more dangerous pursuits such as Alpine climbing—were part of the popular concept of "muscular Christianity". This celebration of manliness sought to encourage both physical and mental toughness, and to unite physical strength with compassion and service to one's fellow-men. The movement was fostered in the public schools and at Oxford and Cambridge, and by the 1860s was believed by some to have produced "morally-superior" students.[81]

From about 1845 onwards, the intellectual and physical environment of the University also began to change, at first slowly and later more quickly. The railway provided rapid transport to London, allowing easier attendance at meetings of the Royal Society and other bodies: thereby, Cambridge became rather less insular than before. New Tripos subjects were introduced, eliminating the previous stranglehold of mathematics and classics on honours degrees and admission to the fellowship. Regulations for appointment to fellowships were relaxed to allow more open competition on merit. At last, in the 1880s, university lectureships were introduced in some subjects, bringing

[80] Bury (1967), pp.78–86.

[81] Warwick (2003), p.213.

more professional teaching and weakening the previous reliance on private tutors. But private tuition was still common until about 1910, when the personal teaching of small groups, or supervisions, were introduced into the colleges. The way in which many of these changes came about is the subject of the next chapter.

John Venn contrasted his early experiences with the huge changes brought about by the growth of natural science, which began with the building of the Cavendish Laboratory in the 1870s: "As you walk down Pembroke Street you see some seven or eight acres to the right and left of you, covered with buildings devoted to 'Science'". In contrast, sixty years before, and apart from some facilities for medicine, "there was a small table, such as two people might take their tea at; a table not in constant use, but brought into the Arts School three times a week during the May term. . . . The performer at the table was Professor Stokes during his lectures on Physical Optics." Though the professors of mineralogy (Miller) and botany (Henslow) may also have given similar demonstrations, Venn had "some doubts as to this".[82]

By the last two decades of the nineteenth century, Cambridge had fully emerged from its torpor. It had not only accepted the need for more diverse, more professional, and more practical instruction: it had firmly established its place as Britain's leading provider of advanced education, and the preeminent training-ground for researchers in the physical sciences. These improvements were brought about slowly and often reluctantly. The period of our study covers the start, but by no means the end, of this transformation, and many of our wranglers were leading lights in the process.

[82] Venn (1913), p.264.

4.
Teaching at Cambridge

Fellows, Private Tutors and Professors

In the early nineteenth century, the quality of education and the conduct of examinations at Cambridge were haphazard. There were no set academic criteria for entry, and students arrived from disparate backgrounds and with disparate ambitions. Sons of the nobility and of wealthy, landed gentry often had little interest in study and much in self-indulgence. But they formed only a small, if prominent and rowdy, minority. Many students were hard-working and came from backgrounds that were not particularly affluent. The long-term aim of many was to secure a Church of England living. The most able set their sights on obtaining a college fellowship, for which a high place in the final Mathematical Tripos examinations was virtually essential. (Only Trinity College had separate fellowship examinations, which were not restricted to mathematics. Other colleges awarded fellowships on the basis of the Tripos results, including, from 1824, the Classical Tripos.) From the comfortable position of a fellowship, a graduate might train for the priesthood, enter one of the Inns of Court to embark on a law career, or seek a tutorship or professorship in Cambridge or elsewhere. Those wishing to hold a fellowship for more than a few years had to become ordained as Anglican priests, and many fellowships could thereafter be held for life, if the fellow remained unmarried. This situation persisted until 1861, when many changes negotiated by the Statutory Commissioners during 1856–59 came into effect.

As already noted, the teaching duties of fellows were normally light or even non-existent. But, though college life may have been congenial, the fellows in most colleges were not well paid. Most taught for only a few years, augmenting their income by taking private pupils, before moving on to secure professions in the Church or law. Some simultaneously held the endowed Sadlerian Lectureships in mathematics attached to the various colleges.[83]

[83] In 1850, fifteen such lecturers were paid £45 p.a. (and that at Emmanuel College £67–10s). These were the bequest of Lady Sadleir. In some sources but not others the spelling "Sadleirian" is used; we follow that of the University Calendar.

Appointments to these lectureships were made for a ten-year period, following an examination of "skill and sufficiency" by the Professors of Mathematics and Astronomy. According to the long-neglected statutes, the duties of these lecturers were fairly minimal, being restricted to a single one-hour lecture in Latin, each term, with another "explanatory of it on the same day", and also twice-weekly to attend "in their chambers, and receive affably and courteously all students of their College who resort to them for instruction and advice."[84] Some may have taught more seriously than this suggests, but others regarded the lectureships as sinecures. In contrast, the Tutor who was responsible for overseeing the instruction at each college received substantial remuneration. In the larger colleges, particularly Trinity and St John's, instruction was rather better organised than in the smaller ones. Their tutors were more assiduous and college scholarship examinations provided added incentives to the students.[85] Concerned for the welfare of undergraduates, twenty-two St John's fellows led by Francis Bashforth in 1849–50 called for an increase in the college's teaching staff—though twenty-two teaching staff would surely have been adequate if all had pulled their weight.[86]

Because the quality of tutoring provided in the Colleges was at best uneven, almost all students preparing for the Tripos examinations sought the assistance of coaches or private tutors. D.A. Winstanley, himself a Vice-Master of Trinity College, records that during 1781–1824 there were several attempts to prohibit the use of private tutors. But, after this time,

> the private tutors loomed larger and larger, and threatened to become almost the dominant feature in the academic landscape. . . . Among them were mere hacks, who specialised in cramming for the ordinary degree examination. These "coaches", as they were called to distinguish them from private tutors of a better type, were generally men who had not taken honours themselves, and their influence was almost invariably bad. . . .
>
> The private tutors, to whom candidates for mathematical and classical honours resorted, were of a very different and much higher order. Some of them were distinguished scholars, and nearly all of them gave instruction which was a valuable intellectual training and of lasting benefit. . . . For many years all undergraduates, who were candidates for high mathematical honours, clamoured for the teaching of William Hopkins of Peterhouse; and they certainly could reasonably believe that Hopkins possessed the

---

84 *Commissioners' Report* 1852, p.68.

85 See e.g. Smith & Stray (2001).

86 Underwood (2001), Smith (2001).

> secret of success. In 1849, when he had been engaged in private tuition for twenty years, he claimed to have had among his pupils one hundred and seventy-five wranglers, of whom one hundred and eight had been in the first ten, forty-four in the first three, and seventeen had been senior wranglers and in 1854 seven of the first nine wranglers, including the first three, were his pupils.[87]

However, Winstanley's distinction between "coaches" and the better class of private tutors is not supported by later historians. It seems, rather, that the terms were used interchangeably.[88]

Like Winstanley, the Cambridge mathematician and historian Walter W. Rouse Ball was also critical of the system. Though he paid tribute to Hopkins and E.J. Routh, "The scandal of the system consisted in the fact that the men were compelled to pay heavy fees to the University and Colleges for instruction, and yet found it advantageous to go elsewhere at their own expense to get it."[89] Charles Bristed confirmed that a private tutor was "an ordinary and almost absolutely necessary feature in the college life of every student, rich or poor," despite regular attendance at college lectures each morning:

> To working up a clever man whose previous training has been neglected, in cramming a man of good memory but no great brilliancy, in putting the last polish to a crack man and quickening his pace, so as to give him a place or two among the highest in either Tripos—in such feats a skilful tutor will exhibit consummate jockeyship; he seems to throw a part of himself into his pupil and work through him.[90]

In a graduation address at Edinburgh University fourteen years after his own at Cambridge, P.G. Tait (1st, 1852) recalled

> eagerly scanning examination papers of former years, and mysteriously finding out the peculiarities of the Moderators and Examiners . . .

[87] Winstanley (1940), pp.411, 412. Winstanley's information on Hopkins' success comes from Gunning (1854), v.2, p.359, who got it directly from Hopkins.

[88] This meaning of the word "coach" was first used around 1830, probably in Oxford. It suggested rapid progress in return for payment, like the quickest mode of transport, such as the Times coach which in 1820 took about five and a half hours to travel between Cambridge and London: Warwick (2001), pp.89–93.

[89] Rouse Ball (1911–12), p.321.

[90] Bristed (1852), v.1, pp.24, 204.

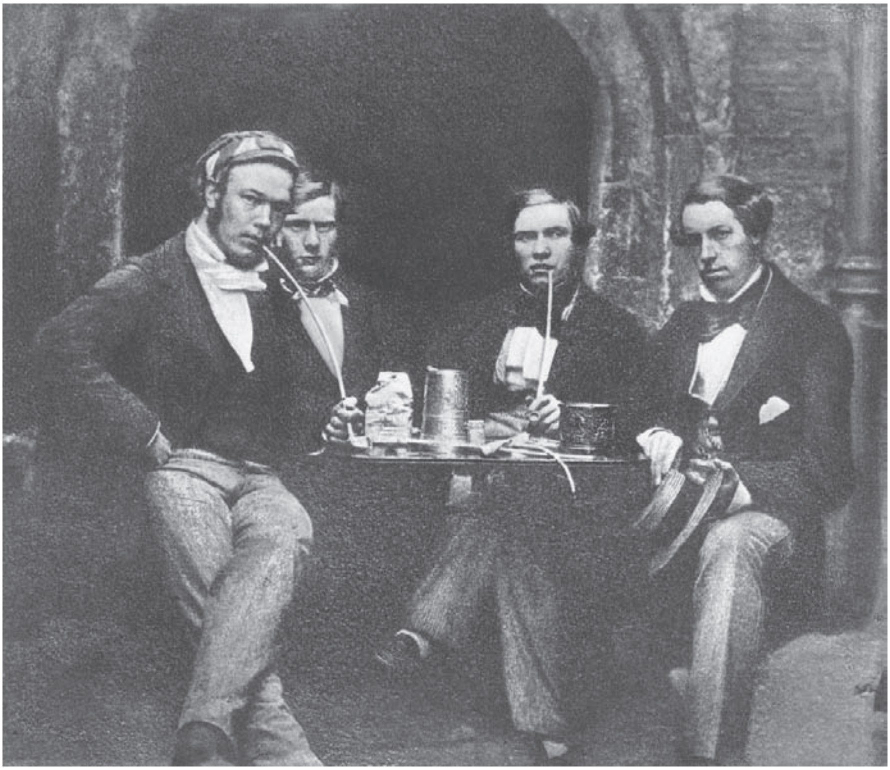


Figure 3. An early photograph of Cambridge students, c.1851: P.G. Tait is on the extreme left and W.J. Steele is third from the left. Note the long clay pipes and beer tankards. [From Knott (1911), facing p.11.]

> discovering which pages of a textbook a man ought to read and which will not be likely to "pay." The value of any portion as an intellectual exercise [was] never thought of . . . . But I hope such a system may never be introduced here.[91]

In some colleges, but not others, college tutors had a close relationship with the private tutors. In the early 1820s, the best tutors were Richard Gwatkin of St John's and George Peacock of Trinity, who taught both in college and privately. In 1826, the year before Hopkins himself graduated, John Hymers of St John's was second wrangler. He wrote popular textbooks, and for a time

[91] Quoted in Knott (1911), p.11.

he and Gwatkin were William Hopkins' most serious rivals as private tutors for able students. Though Hymers and Gwatkin doubtless contributed to their college's success, Hopkins coached at least eight of the seventeen senior wranglers from St John's during 1827–60, presumably with the others' approval. Trinity, and many of the smaller colleges, also farmed out their best students to Hopkins, whose intensive methods produced a high success rate. Thus, at Peterhouse, the college tutor Henry W. Cookson consulted Hopkins before arranging that the brilliant young William Thomson read first with Frederick Fuller, and then, from his second year, privately with William Hopkins himself.

From about 1830, an annual feature in the activities of private tutors was the summer reading party, attended by the majority of pupils whose parents could afford the extra fees. In relaxed surroundings in the hills or at the sea-coast, there was time for outdoor pursuits, but much good work was also done in preparation for the coming examinations. But long before then, Cambridge students had sought out private tutors in the Lake District and the Yorkshire Dales at a time when the practice was discouraged by the University. The most remarkable of these early tutors was John Dawson of Sedbergh, who between 1781 and 1800 trained no fewer than eleven Cambridge senior wranglers and doubtless many lower wranglers besides. One of his pupils was the young Adam Sedgwick.[92]

A rather eulogistic miscellany entitled *The Cambridge Portfolio* (Smith 1840) includes a piece on "Reading Parties" by one "I. S." He extols the advantages of young private tutors, who exerted real influence over their charges with "a total absence of that restraint which more advanced years would necessarily create." Groups of students as small as two or three in number, but sometimes as many as eight to twelve, travelled with their tutors to Wales, Cumberland, Devon, Norfolk, the Scottish Highlands, and even Killarney and Boulogne. Study in the morning and evening was combined with outdoor activities such as hiking and swimming in the afternoon. Usually, there was an examination on Saturday mornings, followed by an excursion:

> But true it is, sometimes the pleasures of boating or fishing are found more fascinating than the Odes of Horace or the Socratic dialogue:—and many enterprising spirits are found, who would rather scale precipices and explore mountain wilds, than spend their time in quiet reflection on the

---

[92] John Dawson (1734–1820) was a medical doctor and a self-taught mathematician with no direct Cambridge affiliation: Warwick (2003), p.62; Fox (2004b).

> Laws of Motion. There are times too, when the youthful spirit . . . meets with fair forms and bright eyes . . .[93]

William Hopkins led such reading parties each summer, to destinations that included Cromer in Norfolk, Barmouth in North Wales, and Boulogne in France.

Before 1850, the final Senate House examinations were devoted exclusively to mathematics. Though there were professorships in a wide range of subjects, and most (but not all) professors gave at least some lectures, these lectures were mostly unconnected with the material required for the examinations that determined the order of merit of candidates. As a result, attendance at professorial lectures was predictably low.

Solomon Atkinson's cutting observations on the mathematicians he encountered in the 1820s have the ring of truth. Robert Woodhouse, the Lucasian and then Plumian Professor between 1820 and 1827,

> has added little or nothing to the stock of science. . . . [But] he has written a multitude of elementary treatises, most of them very excellent, and laid the foundations for introducing the continental methods in Cambridge, which was completed by a bold measure of Mr Peacock of Trinity.

"Mr. W—l" [Whewell] impressed him, but had until then devoted too much time to textbook-writing; while

> Mr P—k [Peacock] . . . one of the translators of Lacroix, and one of the compilers of the Supplement of Examples . . . has a clear head and a prodigious industry, has read more mathematics probably than any three men of his age now living; but he does not possess a single particle of invention.

As for Richard Gwatkin,

> Mr G—n, a lecturer at St John's, [is] the neatest and most clear-headed mathematician in Cambridge, the best private tutor, and the best mathematical lecturer in the University. He is an excellent moderator, and his examination papers are models of clearness and judgment. Of any other

[93] The writer claimed that such visits also benefited the local community: "something is done to strengthen that union between the different ranks of society, which has always been at once the ornament and the safeguard of our nation": Smith (1840), pp.252, 253.

> knowledge, whether of the most ordinary affairs of life, or of questions which occupy the public mind, or are likely to influence the public happiness, he is as innocent as an Esquimaux.[94]

But, as noted above, Atkinson reserved his sharpest barbs for Joshua King, a man who "*might* have been one of the first mathematicians of Europe" who wasted his talents and time on college administration, whist and drinking.

R.M. Beverley was another who chided Cambridge mathematicians for their lack of distinction, claiming that "the most eminent mathematician of England is at the present time a lady! Mrs [Mary] Somerville has passed by the flaming walls of Cambridge, . . . has dimmed all the college stars into pale obscurity."[95]

Though the final Tripos examinations, taken in January of the students' fourth year, concerned only mathematics, students were at least exposed to a few other fields of learning in their first two years at Cambridge. Then, the emphasis was on Latin, Greek, and theology, which were examined in the so-called "Previous" or "Little-Go" examinations at the end of the second year. Some colleges, notably Trinity and St John's, held their own college examinations as a further means of providing incentive to study: college scholarships, prizes and medals were awarded on the basis of these.[96]

Though classics and theology were taught in the colleges, and were judged an indispensable acquirement for future priests and vicars, it was not until 1824 that a voluntary Classical Tripos examination was begun, held shortly after the Mathematical Tripos examinations and available only to those who had first obtained mathematical honours. The latter restriction was finally abolished as part of the reforms of 1850, when two further Tripos subjects, Natural Sciences and Moral Sciences, were added to Mathematics and Classics. A few years later, in 1856, honours examinations in theology were also introduced.

---

94 Atkinson (1825a), pp.504, 505. A supporting anecdote about Gwatkin is told by John Delaware Lewis. On returning from a reading party to Wales, "Rev. Mr. G., Senior Wrangler of his year, and fellow of St John's College" was asked whether they had climbed Snowdon; at first bemused, he replied that "the little hill behind the house where we were lodging [was] quite high enough for all practical purposes": Lewis (1849), p.9.

95 Beverley (1833), p.39.

96 Trinity College also held examinations for the fellowship, open only to scholarship holders and taken after graduation. These examinations tested knowledge of Greek and Latin as well as mathematics. In contrast, other colleges awarded fellowships on the strength of the Tripos results alone.

From 1815, there were classes and examinations in Civil Law, which led to the degree of Bachelor of Laws (LL.B.). This provided a "refuge for many weak students who could not face grinding at geometry for ten terms", and standards were not high.[97] The common attitude to these law students was that held by Henry Fawcett, that "A Senior Wrangler . . . might be absolutely ignorant of law; but three years after his degree he would be a far better lawyer than the men who had been crammed with legal knowledge in place of being trained in the use of his logical faculties."[98] A more reputable Law Tripos was introduced in 1858.

The first professor of medicine was appointed in 1800, and Bachelor of Medicine (M.B.) degrees were awarded from around 1817. But clinical examinations did not begin until 1842, and John Haviland, the Regius Professor of Medicine, reported to the 1850 Commission that medical studies were still at a very low ebb. Only from the mid-1860s was a credible five-year training course established; and it was not until the 1880s, under the professorship of George Edward Paget (8th, 1831), that adequate arrangements for clinical teaching were put in place.[99]

The majority of professorships were endowed by individual benefactions which usually included rents on property. Accordingly, the stipends of professors varied greatly and bore no relationship to the duties performed, nor to the scholarly eminence or obscurity of the incumbents. Their official duties were minimal, confined to a few lectures each year, and even these were not always given. In 1850, the Lady Margaret Professor of Divinity was the highest paid, with the huge income of £1854 per annum, whereas the Lucasian Professor of Mathematics (the post once held by Isaac Newton) was one of the poorest, with £157 p.a.[100] The outstanding George Gabriel Stokes, one of Hopkins' former pupils, was appointed Lucasian Professor in 1849. He voluntarily gave courses of lectures each year; but, to augment his income, during 1854–60 he took a second job as Professor of Physics at the Government School of Mines in London. In contrast, Herbert Marsh, appointed Lady Margaret Professor of Divinity in 1807 and also Bishop of Peterborough, reportedly gave a total of thirty-four lectures from St Mary's pulpit during his twenty-eight-year tenure, and other professors gave none at all.[101]

97 Searby (1997), p.190.

98 Stephen (1885), p.91.

99 Searby (1997), pp.199–201.

100 *Commissioners' Report* 1852, pp.71–73. In the 1860s, the salaries of the Lucasian and Plumian professors were increased to more appropriate levels.

101 "A Graduate of Cambridge" (1836), pp.41–44.

From about 1860, all candidates for the ordinary "poll" degree (but not honours students) were required to attend some professorial lectures; but most of these students complied with the letter, rather than the spirit, of the regulation and did not study seriously. Furthermore, the regulation explicitly excluded the lectures of the mathematical professors. By the 1880s, the virtually invisible role of the professors had not much changed, despite two Royal Commissions. A.R. Forsyth, Sadlerian Professor of Pure Mathematics from 1895 to 1910 and senior wrangler in 1881, reminisced about his "Old Tripos Days at Cambridge":

> Between the great professors and our unfledged selves there was nothing in common, absolutely nothing, strange as such a declaration may seem. They did not teach us: we did not give them the chance. We did not read their work: it was asserted, and was believed, to be of no help in the Tripos. Probably many of the students did not know the professors by sight. Such an odd situation, for mathematical students in a University famed for mathematics, was due mainly, if not entirely, to the Tripos and its surroundings which, as undefined as the British constitution, had settled into a position beyond the pale of accessible criticism.

G.G. Stokes' course of lectures on Physical Optics "was the single professorial exception allowed, even enjoined, by tutors of all grades—and delightful the lectures were, none the worse because they were of no profit in a Tripos Examination."[102]

Reforms of Mathematics in the Early Nineteenth Century

Early in the nineteenth century, belated efforts had been made in Britain to replace Isaac Newton's "method of fluxions" with the more flexible differential and integral calculus that originated with Gottfried Wilhelm Leibniz. Newton's theory of fluxions had evolved from around 1665, and Leibniz's first papers on the differential and integral calculus appeared in 1684 and 1686, before any of Newton's work had been published. A chauvinistic priority dispute did no credit to the supporters of either side, and condemned British mathematics to a period of insularity. Meanwhile, the "continental calculus"

[102] Forsyth (1935), pp.166, 162.

was further developed, and fruitfully applied to new fields of study, most notably by Johann Bernoulli, Jean d'Alembert, Leonhard Euler, Joseph Louis Lagrange and Pierre Simon Laplace.

But changes in Cambridge were painfully slow. At a relatively early date, Robert Woodhouse had adopted the continental notation and surveyed some of the leading French work in his *The Principles of Analytical Calculation* (1803), but this had little or no effect on undergraduate teaching. Though a professor during 1820–27, which was a time of significant change, Woodhouse was by then mainly preoccupied with his astronomical duties at the new Cambridge Observatory. But his works on plane and spherical trigonometry (1809), on the calculus of variations (1810), and two on astronomy (1812; 1818) were the first student texts to illustrate the power of analysis in problem-solving.[103]

Among the first to express concern about the state of British mathematics were John Toplis, a Cambridge-educated headmaster in Nottingham, and John Playfair of Edinburgh University.[104] Playfair's 1808 review of the first four volumes of Laplace's revolutionary *Mécanique Céleste* concludes with a lament that, unlike earlier times, hardly a British name deserved inclusion among the list of mathematicians and philosophers who had contributed to the progress of physical astronomy during the past sixty or seventy years. He complains that:

> a man may be perfectly acquainted with every thing on mathematical learning that has been written in this country, and may yet find himself stopped at the very first page of the works of Euler and D'Alembert. He will be stopped, not from the difference of the fluxionary notation, (a difficulty easily overcome,) nor from the obscurity of these authors, who are both very clear writers, especially the first of them, but from want of knowing the principles and the methods which they take for granted as known to every mathematical reader. If we come to works of still greater difficulty, such as the Mécanique Céleste, we will venture to say, that the number of those in this island, who can read that work with any tolerable facility, is small indeed. If we reckon two or three in London, and the military schools in its vicinity, and the same number at each of the two English Universities, and perhaps four in Scotland, we shall not hardly exceed a dozen; and yet we are fully persuaded that our reckoning is beyond the truth.

103 Phillips (2006).

104 Toplis (1805); Playfair (1808; 1822).

Though there was still widespread interest in mathematics in the country at large, as evidenced by the popularity of the mathematical problems of the *Ladies' Diary*, the cause of the deficiency lay "in the public institutions of England . . . and particularly in the two great centres from which knowledge is supposed to radiate over all the rest of the island." In one [Oxford], "the mathematical sciences have never flourished; and the scholar has no means of advancing beyond the mere elements of geometry." Playfair admits that, in contrast, mathematics is much studied at Cambridge; but he objects that candidates for mathematical honours must there submit to such a tedious system of rote-learning that their invention and curiosity are not aroused. The Royal Society, too, had failed to encourage mathematical learning as it should.[105]

Outside Cambridge, there were translations and reworkings of the early parts of Laplace's *Mécanique Céleste* by John Toplis and by Thomas Young.[106] Two former students of Playfair, James Ivory and William Wallace, both worked at the Royal Military College, Marlow (later at Sandhurst), and used the continental analysis to good effect but with only limited impact. Indeed, Wallace's lengthy, but apparently little-read, article on "Fluxions" in the *Edinburgh Encyclopaedia* of 1815 was the first comprehensive English-language account of differential and integral calculus to use the improved "continental" notation; and an even earlier survey of continental analysis by John West went unpublished until 1838. Other early practitioners of the "continental analysis" were Charles Hutton at the Royal Military Academy at Woolwich and John Brinkley and Bartholomew Lloyd in Dublin (but Hutton's *A Course of Mathematics . . . for the Use of the Gentlemen Cadets in the Royal Military Academy at Woolwich* steadfastly retained Newton's fluxional notation). At the Belfast Academical Institution, James Thomson also supported the continental analysis; and he was the probable author of reviews in the *Belfast Magazine* for 1825 on the state of science in Ireland and in Scotland, which echo Playfair in

---

105 Playfair (1822), v.4, pp.324–330. Twenty-four years after Playfair criticised Oxford's lack of mathematics, Baden Powell, Oxford's Savilian Professor of Geometry, lamented that "it is a most glaring reproach to us to send out . . . a host of Batchelors of Arts, profoundly ignorant of the most common principles of Science": Powell (1832), p.26. Then, most honours students studied Classics together with some logic, and only a few chose mathematics instead. As late as 1887, a despondent J.J. Sylvester complained that "It seems to me that Mathematical Science here is doomed and must eventually fall off like a withered branch from a Tree which derives no nutriment from its roots": see Parshall (2006), p.302.

106 Toplis (1814); Young (1821).

deploring British ignorance of the continental mathematicians. Two other British mathematicians, Thomas Knight and William Spence, skillfully used analytical methods in isolated circumstances and were almost completely ignored.[107]

Reform in Cambridge was finally accomplished by the early 1820s, after the famous 1812 creation of the undergraduate Analytical Society led by Charles Babbage, John Herschel, George Peacock, Richard Gwatkin and some others.[108] In 1813, they published a volume of analytical memoirs, which shows the influence of Woodhouse. And, to further the Society's aims, Babbage, Herschel and Peacock published in 1816 an English translation of Silvestre F. Lacroix's *Traité Élémentaire du Calcul Différentiel et du Calcul Intégral*, thereby providing the first convenient English account of the continental version of the calculus. There followed two books of challenging worked and unworked examples, by Peacock and much later by Duncan Gregory.[109]

The mere adoption of Leibniz's notation in place of Newton's was less important than is generally made out: John Playfair rightly said that this was a difficulty easily overcome. But the change of focus brought a new awareness of the developments of the calculus at the hands of Euler, d'Alembert, Lagrange, Laplace and other continental *savants*. A crucially important fact is that Peacock (2nd wrangler, after Herschel, in 1813) and Gwatkin (senior wrangler 1814) subsequently became Fellows of Trinity College and St John's College respectively. As moderators and examiners in 1817 and several years after, they introduced Tripos questions which used the "new" (in fact about 130 years old) notation, and they gave personal tuition to the most promising undergraduates.

J.M.F. Wright's remarks about the mathematics of his day show that he studied not only English texts, but French works too. Among the latter, "Lacroix's three quartos on the Differential and Integral Calculus frightened [him] most." In his second year, he met works on algebra by Garnier and Lacroix, and had at least some acquaintance with Laplace's *Système du Monde*, Lagrange's *Calcul des Fonctions*, and Arbogast's difficult *Calcul des Dérivations*. In his third year, he was reading Françoeur's "*Math. Purées*" [sic!] and "perused several of the excellent productions of Bossut, of Lacroix, and Garnier" as well as the first section of Lagrange's *Méchanique Analytique*.[110]

[107] Guicciardini (1989); Panteki (1987); Craik (1998; 1999; 2000; 2004); Smith & Wise (1989, pp.17, 18).

[108] Enros (1983).

[109] Lacroix (1802; 1816); Peacock (1820); Gregory (1841).

[110] Wright (1827), v.1, pp.9, 206, 207, 225, 226; v.2, pp.25–29.

Wright began his studies at Cambridge in 1815, just three years after the 1812 foundation of the student Analytical Society that promoted French analytical mathematics. This shows the rapidity with which mathematically inclined Cambridge students embraced the "new" French analysis once it had been introduced.

But there was still a shortage of suitable texts in English: in his second year, Wright sought "Problems and Deductions" in the *Ladies' Diary*, the *Gentlemen's Diary* and *Dodson's Repository*, as well as all the past examination papers he could lay his hands on. The college libraries were not much help. Apart from those at Trinity and St John's, few bought new books suitable for students; and, in most colleges, undergraduates could visit the library only if a fellow could be found to accompany them. As for the richly stocked University Library, undergraduates were prohibited from entering it until 1854; and, from 1854 to 1875, their access was limited to just two hours per day.[111]

It has been suggested that Solomon Atkinson beat Gwatkin's St John's men by "hard work, an excellent memory, and a thorough grasp of . . . relatively elementary mathematics", and that "Gwatkin's enthusiasm for the new mathematics might actually have prejudiced his students' chances."[112] But if Wright was reading French texts at Peacock's college of Trinity, then surely Atkinson, a friend of G.B. Airy, was doing so too.

The gifted George Biddell Airy entered Trinity College as an undergraduate in 1819 and was given personal instruction by Peacock. In due course, Airy became Lucasian Professor of Mathematics, and later succeeded Woodhouse as Plumian Professor of Astronomy and Experimental Philosophy, before his appointment as Astronomer Royal at the Greenwich Observatory. Airy's influence on the teaching of applied mathematics was as great as Peacock's had been in pure mathematics. His *Mathematical Tracts* (Airy 1826) applied analytical methods to problems of astronomy, to the shape of the Earth, and to its precessing and nutating (or "wobbling") motion. They also gave an account of Lagrange's calculus of variations, and later editions included the wave theory of light. The earlier textbooks of Woodhouse soon fell from favour. For many years, Airy's work set the tone for the University's Smith's Prize examinations and those parts of the Tripos devoted to advanced applications of mathematics. Airy's lectures as Lucasian Professor during 1827 and 1828 were unusually well attended: they dealt with applications of analysis to

[111] McKitterick (2001).

[112] Warwick (2003), p.76.

Figure 4. Portrait of G.B. Airy. [From Airy (1896), frontispiece.]

mechanics, optics, pneumatics (i.e. motion of gases) and hydrostatics. But Airy's *Mathematical Tracts* was not an easy text for self study: he rarely starts from first principles and takes much for granted as already known from more elementary works. Without help from knowledgeable tutors, Airy's *Tracts* could not have exerted the influence that it did.[113]

William Hopkins was an undergraduate during 1823–27, and would certainly have attended Airy's lectures. He therefore belonged to the first wave of Cambridge students equipped with these new techniques of pure and applied mathematics. Soon after, as private tutor to many of the best students, he held a key position in passing on these advances to the next generation. In turn, these recent graduates became fellows and supported what has been termed "the analytical revolution from below".[114] But one might dispute the epithet "below", for these young college fellows served not only as tutors but

[113] One writer complained that the reasoning of Airy's tract on "Gravitation" "is far above the grasp of an *ordinary* mind. I am well acquainted with many high *Wranglers* who confess that they are quite incapable of understanding Professor Airy's 'Gravitation' ": "A Graduate of Cambridge" (1836), p.36.

[114] Warwick (2001).

also as moderators and examiners, and so were in the best place to influence directly what was taught. Hopkins, and a few other private tutors, were able and willing to oblige.

In contrast, the professors had little or no involvement in the revolution that was taking place. Indeed, until the Board of Mathematical Studies was set up in 1848, there was no centralised control over the syllabus, and the moderators had a free hand to set whatever they liked, guided by recent precedents. Though much basic material was unalterable, there was considerable latitude for change at the advanced level. In this way, much power and responsibility fell into the hands of rather junior college fellows. It was because these recent graduates had such effective control of the examinations that the "analytical revolution" was so quickly accomplished, once begun.

Most examiners and moderators were junior fellows who first served four to six years after their own B.A. graduation. Between 1837 and 1850, there were twenty-one different moderators and examiners (two of each for each year), none of whom served for more than four years in all. The moderator set the question paper and the examiner helped with the marking. Often, the examiner became the next year's moderator. Though William Hopkins, not being a fellow, was ineligible to take part, at least fourteen of his former pupils acted as examiners or moderators in this fourteen-year period. We say "at least" because we count only those present in the Wren Library album: several more were his pupils, and Hopkins' indirect influence must have been very great.

Many students arrived at university knowing little geometry and algebra, whereas others had already received a thorough grounding. Some had mathematical aptitude of the highest order, whereas others knew little and cared less. College tutors had the unenviable task of catering for very disparate needs, and it is not surprising that their lectures were largely unsuccessful. But the best private tutors were able to select or reject pupils as they wished. Hopkins, in particular, had his pick of most of the high-flyers; and his classes, of no more than ten able and well-motivated students, must have been a joy to teach. At the other end of the scale, the lower class of coach who specialised in cramming weak students to pass the ordinary "poll" degree examination provided little of educational value.

From 1828, the first two days of the four-day Tripos Examinations in mathematics were customarily devoted only to elementary topics. This suited the less-gifted students who struggled to master the differential and integral calculus (if they bothered); but it also ensured that the abler students had a firm grasp of foundations. Later, the number of days of the Examinations increased, with the first few days still devoted to elementary topics. The 1849 Report of the recently founded Board of Mathematical Studies describes these subjects as:

> the portions of Euclid usually read; Arithmetic; parts of Algebra, embracing the Binomial Theorem and the Principles of Logarithms; Plane Trigonometry, so far as to include the solution of Triangles; Conic Sections, treated geometrically; the elementary parts of Statics and Dynamics, treated without the Differential Calculus; the First three sections of Newton, the Propositions to be proved in Newton's manner; the elementary parts of Hydrostatics, without the Differential Calculus; the simpler propositions of Optics, treated geometrically; the parts of Astronomy required for the explanation of the more simple phenomena, without calculation.[115]

The emphasis on *applications* of elementary mathematics is noteworthy, and a traditional strength still associated with Cambridge: only the requirement that propositions be "proved in Newton's manner" seems retrograde.

In the more advanced papers, the greatest analytical complexities arose through applications, and can often be traced to Airy's lectures and his *Mathematical Tracts*. Just how analytical some of these had become is evident from the topics which, in 1850, the Board of Mathematical Studies decided to *exclude* from the Tripos examinations. Among the topics recommended for exclusion were elliptic functions, Laplace's coefficients (now more properly called Legendre functions), capillary attraction, and some of the more technical applications of mathematics to hydrodynamics, optics and astronomy. Applications to heat, electricity and magnetism were still regarded as highly speculative, and had been dropped the year before, following the 1849 Report. But some difficult topics remained, such as the theory of gravitational attraction, and the shape of the rotating self-gravitating Earth (assumed to be a uniform liquid).

Peacock's "Statutes" and Whewell's "Liberal Education"

As a founder of the Analytical Society and then an influential fellow and tutor at Trinity College, George Peacock had a key role in the revival of Cambridge mathematics. He was also much involved, with Robert Woodhouse, in establishing the University observatory in 1822–24. In 1836, Peacock defeated William Whewell in gaining the Lowndean Professorship of Astronomy and Geometry, in succession to W. Lax. Though he promised "to do his duty in a less lax manner than his predecessor", he became Dean of Ely three years

[115] Reproduced in *Rept.*, p.232.

later and was then largely an absentee.[116] The loss of Peacock to mathematics was counterbalanced by the much-needed restoration of Ely Cathedral, which he expertly supervised. He continued to hold the Lowndean chair until his death in 1858.

Despite his absence, Peacock maintained a close interest in the University, and in 1841 he published highly critical *Observations on the Statutes of the University of Cambridge* (Peacock 1841). He favoured reducing the course length of the B.A. degree from ten terms, taking three and a bit years, to eight terms, finishing at midsummer of the third year. He was also keen to limit the powers of examiners, so as to restrict the examinations to a well-defined, more-limited syllabus, and thereby reduce dependence on private tuition.

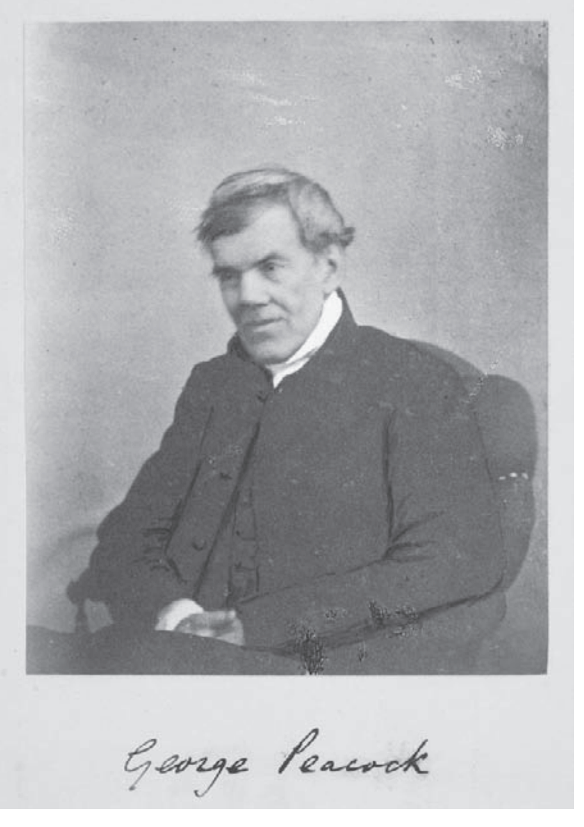


Figure 5. Photograph of G. Peacock. (FA1.5: courtesy of the Master and Fellows, Trinity College, Cambridge.)

[116] Clark & Hughes (1890), v.1, p.473.

He believed the recent rapid growth of private tuition to be "an evil of the most alarming magnitude," that not only caused great expense but threatened to supersede the public instruction in the colleges and in the university. He estimated the total expenditure on private tuition at around £52,000 per annum, "more than three times the sum paid to the whole body of public tutors or professors in the university." The system harmed both pupils and private tutors: the tutor lacked stimulus, "his spirits . . . exhausted by the weary and uninteresting labour"; and the student, "whose difficulties are thus smoothed over without labour or research, is too frequently enervated by this perpetual pampering of his appetite for knowledge, without the necessity of digesting that less palatable food which original enquiry must perpetually present." Many tutors were inexperienced young men of limited talent, who began tutoring as soon as they left the care of their own private tutor.

Peacock maintained that, despite the academic distinction of the professors, and their willingness to discharge their public duties conscientiously (a debatable point), they could hardly muster enough students to justify giving lectures: "No subject, however interesting, no treatment of it, however luminous and instructive, can long withstand the absorbing influence of the private tutors, or of those studies which are immediately concerned with the examination for degrees." His preferred solution was to ban private tutors from all but the first year of study; but he acknowledged that this would inflict hardship on some very able men who made a living from tutoring. In an obvious reference to William Hopkins, he says that:

> All the members of the university will single out one name equally distinguished for the great extent and the philosophical character of his attainments, and of his great skill and pre-eminent success as an instructor of youth; and it would be easy to select other accomplished scholars and mathematicians, who fully deserve a more ample field for the exercise of their talents.[117]

Perhaps such men might be recruited to teach within the university or at institutions elsewhere. Those who presently spent their time in tutoring and in writing elementary works would be capable, in another environment, of forwarding the progress of science and learning.

Though Peacock was repeating sentiments that had been expressed many times before, both by former students such as Atkinson and Bristed, and by would-be reformers from outside Cambridge, this time the criticism came

---

117 Peacock (1841), pp.151–155, 156.

from an insider, one of Cambridge's most respected professors. And his intimate knowledge of the current regulations enabled him to make specific recommendations for their amendment. Though these recommendations predictably had no immediate effect, they helped to focus the debate about reform; and, given his strong views, Peacock's appointment to the 1850–52 Royal Commission (discussed in the next section) must have been viewed with concern by many.

Like Peacock, William Whewell, the influential master of Trinity College from 1841 to 1866, had been an early supporter of the introduction of analytical methods. He was Professor of Mineralogy in 1828–32 and Professor of Moral Philosophy (or, more precisely, the quaintly titled Professor of Casuistry) in 1838–55. Starting off as a mathematician (he was 2nd wrangler in 1816), Whewell had wider ambitions: his work encompassed geology, crystallography, the tides, architecture, economics, history and philosophy of science, moral philosophy, Plato's *Dialogues*, translation of classical and German texts into English hexameters, and the theory of education. Sydney Smith's much-quoted assessment of Whewell was "that omniscience was his forte and science his foible."[118]

Whewell succeeded Christopher Wordsworth as Master of Trinity College in circumstances already described. According to Charles Bristed:

> . . . this event was anything but welcome to the majority of both Fellows and Undergraduates, who . . . would certainly have chosen either Dean Peacock or Professor Sedgwick to rule over them. Their repugnance towards a gentleman so distinguished arose from some unfortunate propensities of his, which had been conspicuous enough during his Tutorship, and which it was correctly supposed would be rather intensified than diminished by his elevation. The Professor of Casuistry was an intolerably *fussy* man—a rigid martinet, weakly punctilious about trifles. . . .
>
> . . . While leaving untouched actual abuses (of which Trinity, like most old institutions, could boast a few fat ones), our new Master enforced petty and long neglected regulations about walking over grass-plots, and crossing the court without a cap or gown at certain hours; he revived obsolete laws against the domestic variety of tiger, which interdicted the possession of that useful animal to any but Noblemen or Fellow Commoners.[119]

[118] Fisch & Schaffer (1991); Bristed (1852), v.1, p.122.

[119] Bristed (1852), v.1, pp.122, 123.

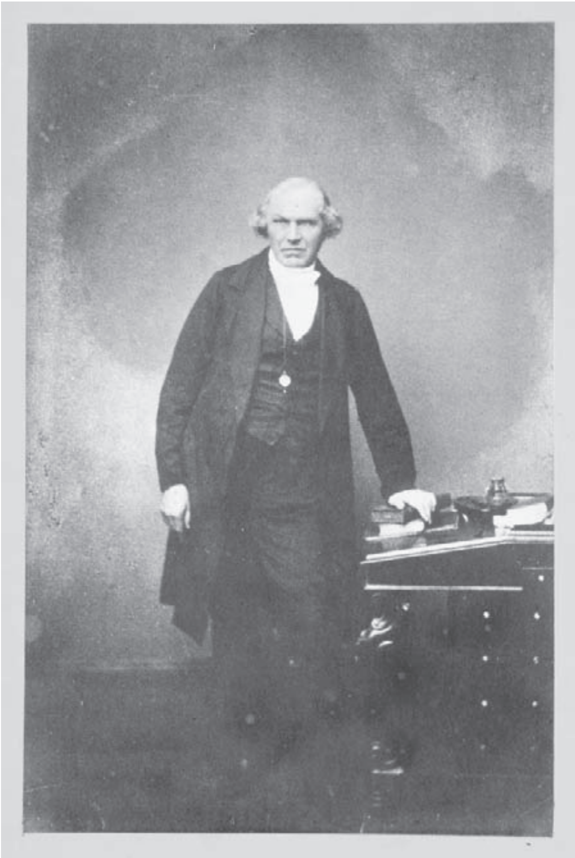


Figure 6. Photograph of W. Whewell. (FA1.6: courtesy of the Master and Fellows, Trinity College, Cambridge.)

Whewell also let it be known that, when invited to the Master's Lodge, students should not sit down in his presence. He added to his unpopularity through an attempt to improve the quality of mathematics at Trinity by demanding higher mathematical attainment for the award of scholarships. Because this change applied to students aiming for top classics degrees as well as to mathematicians, it was considered unfair, and more likely to harm Trinity's superiority in classics than to rival that of St John's in mathematics.[120]

[120] Bristed (1852), v.1, p.125.

Whewell's autocratic behaviour was legendary: and D.A. Winstanley, Vice-Master of Trinity College in the middle of the twentieth century, recounts one notorious example. In 1855, Whewell was Vice-Chancellor of the University for the second time. He was also an *ex officio* member of the syndicate in charge of the Fitzwilliam Museum, which was then being redecorated. Without consulting the other syndics, Whewell proceeded to rehang the museum's paintings as he saw fit. Concerned that nude figures in the main public gallery were unsuitable for viewing by the young, he relegated several Renaissance masterpieces to less-visible locations, and even covered one with a green curtain. The other syndics were appalled, and most resigned in protest. It was the unrepentant Whewell's responsibility to recommend new syndics to the Senate, but he found few willing to be nominated. In the end, a compromise was found that avoided his total humiliation: a committee was formed to consider what changes, if any, should be made "in the constitution, duties and powers of the Fitzwilliam Syndicate." Winstanley's assessment of Whewell is vitriolic: "He possibly might have been very successful as the leader of a totalitarian state, but the defects of his character prevented him from acquiring that influence in the University which was really his due."[121]

Despite his unpopularity with students, Whewell had strong views about how and what they should be taught, and how the University should be organised. In the early 1830s, he and George Peacock championed the building of a new university (as distinct from college) centre for science; but the two quarreled over the plan and the Senate rejected their proposals. Later, Whewell and Peacock combined to establish the Board of Mathematical Sciences to oversee the Mathematical Tripos. And it was largely through Whewell's campaigning that the Natural Sciences Tripos and Moral Sciences Tripos were established in 1851.[122]

In 1835, Whewell had published his *Thoughts on the Study of Mathematics as a Part of a Liberal Education*, soon followed by a second edition. In this, he set out to discredit hostile views of mathematics: though some believed that

> mathematics is a most admirable mental discipline; that it generates habits of strict reasoning, of continuous and severe attention, of constant reference to fundamental principles: on the other side it is asserted, that mathematical habits of thought unfit a man for the business of life;—make his mind captious, disputatious, over subtle, over rigid;—that a person inured

[121] Winstanley (1940), Ch. IX, pp.139, 146.

[122] See Becher (1991).

> to mathematical reasoning alone, reasons ill on other subjects, seeks in them a kind and degree of proof which does not belong to them, becomes insensible to moral evidence, and loses the finer perceptions of fitness and beauty, in which propriety of action and delicacy of taste must have their origin.[123]

But he argues that mathematics is beneficial only if well taught, properly treating the basic principles, rather than emphasising arbitrary definitions and empirical rules based on observation, and so revealing the "vast solid evidences of truth independent of sensory evidence, based on 'necessary truths'."

This rejection of "sensory evidence" led to criticism by William Hamilton in the *Edinburgh Review*, who rightly saw it as disregarding the experimental observations that underpin all sound applications of mathematics. But Hamilton, keen to promote logic and philosophy, also cast doubt on the wider intellectual value of those parts of mathematics that employed algebra and analysis. Whewell responded in the second edition of his work; and another eloquent defence of the intellectual benefits of mathematics, natural philosophy and astronomy was made by Temple Chevallier (2nd, 1817), Durham University's Cambridge-educated Professor of Mathematics. According to Whewell, the mathematical pursuits of "lawyers, or men of business, or statesmen . . . have in no small degree regulated their mode of dealing with other subjects." For lawyers, in particular, there was an "extraordinary coincidence of professional eminence in after-life with mathematical distinction in their university career."[124]

Whewell outlined his preferred mathematical syllabus, placing emphasis on Euclidean geometry, mechanics, hydrostatics and the concept of limits applied to the differential calculus. His early analytical enthusiasm had waned, and he adopts a traditionalist stance extolling the intellectual merits of Euclidean geometry and the discoveries of Isaac Newton. Though geometrical methods were often more laborious than their analytical counterparts that employed "symbolical calculations" of algebra or calculus, he asserts that the former were often to be preferred in teaching.

Whewell's ambitious *History of the Inductive Sciences, from Earliest to the Present Times* further established his reputation as a wide-ranging scholar. But this work was violently attacked for its élitist intellectual stance by David

---

123 Whewell (1836), p.3.

124 Whewell (1836), pp.9, 40; Hamilton (1836); Chevallier (1836); Williams (1991), pp.121, 122.

Brewster. He lambasted Whewell for ignoring important applications of science to technology—including Babbage's calculating engine, balloons, steamboats, steam-guns, gas illumination, locomotive engines and railways—and also for systematically neglecting or downgrading the major contributions made by Scots.[125]

In 1845, Whewell reinforced his conservative yet reforming position in a more wide-ranging manifesto, *Of a Liberal Education in General; and with Particular Reference to the Leading Studies of the University of Cambridge*. In this, he proposes a complete system of education at the University, giving much detail on his preferred syllabuses in mathematics and in classics. Whewell's vision of a "Liberal Education" has been interpreted as a Tory defence against Whig-inspired calls for change: a modified version of the *status quo*, rather than the radical reform that some wanted. Though himself the son of a carpenter, he was certainly more interested in training the minds of an élite of gentlemen than in making the study of science and technology available to the general population:

> The education of the upper classes of the community is . . . especially important: both because the characters of members of those classes have a greater influence upon the conduct and fortunes of the general body, and because the education of the lower classes will . . . depend upon that of the upper.[126]

Yet Whewell's manifesto is a skillful one, in which he sets out to justify the long-established emphasis on mathematics and classics, while also proposing some structural changes. His importance in persuading his Cambridge colleagues to introduce some measure of reform cannot be over-estimated. He was well aware that if the University did not change itself, then change would be imposed from outside. It is surely no coincidence that the year of 1848, in which the petition for a Royal Commission into the University's affairs was raised, was the same year in which the Board of Mathematical Studies was founded to oversee the Tripos examinations; and that the decisions to free the Classical Tripos from its mathematical prerequisites, and to introduce two new Triposes in Natural Sciences and Moral Sciences, took place just before the Royal Commission began its deliberations.

In his *Liberal Education*, Whewell distinguishes "permanent" and "progressive" studies: only the former need be studied by students not seeking an

---

[125] Whewell (1837); Brewster (1837).

[126] Whewell (1845), p.1.

honours degree, but the best students should also study "progressive" studies. The "permanent" studies are "those portions of knowledge which have long taken their permanent shape:—ancient languages with their literature, and long-established demonstrated sciences" such as mechanics and hydrostatics. He viewed these as fit subjects for the general education of all gentlemen. In contrast, "progressive" studies consist of "the literature of our own age, and the sciences in which men are making progress from day to day." Among the latter are "new branches of pure mathematics, Algebra, the Algebra of Curves, and the Differential Calculus" which "cannot take the place of the Permanent portions . . . without destroying the value of our system." Whereas geometry epitomises "perfect reasoning", he considers that algebra, and branches derived from it, involve the mere application of rules, more suited to a "professional mathematical education" than a liberal one. He believed some recent works to be unsuitable even for honours students: those of Lagrange and Laplace, which applied advanced analysis to mechanics, should form "no part of the standard portion of our educational course", although they might be recommended to outstanding students.[127]

Whewell's antipathy to algebra and analysis was not uncommon at that time. It was perhaps to be expected from scholars well versed in geometrical techniques but less familiar with recent developments, which were threatening to make geometrical expertise redundant as a major investigative tool. In 1838, the Edinburgh logician Sir William Hamilton had attacked his colleagues, James D. Forbes and Philip Kelland, for increasing the emphasis on analytical mathematics in their teaching. Hamilton likened algebraic methods to running a railroad through a tunnelled mountain; and geometrical ones to

> crossing the mountain on foot. The former causes us, by a short and easy transit, to our destined point, but in miasma, darkness, and torpidity, whereas the latter allows us to reach it only after time and trouble, but feasting us at each turn with glances of the earth and of the heavens, while we inhale the pleasant breeze, and gather new strength at every effort we put forth.[128]

It is likely that Whewell knew Hamilton's article, for he used a similar metaphor:

[127] Whewell (1845), pp.5, 6, 28, 29, 35–37; Smith & Wise (1989), pp.61–65.

[128] Quoted in Davie (1961), p.127. This William Hamilton, of Edinburgh, should not be confused with the Irish scholar, William Rowan Hamilton.

> In geometrical reasoning, we tread the ground ourselves, at every step feeling ourselves firm, and directing our steps to the end aimed at. In the other case, that of analytical calculation, we are carried along as in a rail-road carriage, entering it at one station, and coming out of it at another, without having any choice in our progress in the intermediate space. . . . It may be the best way for men of business to travel, but it cannot fitly be made a part of the gymnastics of education.

According to Whewell, analysis did not enhance the powers of reasoning: a general belief in the educational value of mathematics had arisen through the use of geometry, and could not have arisen through analysis. A main aim of mathematics teaching should be to "make men acquainted with those mental triumphs of past generations which have always occupied a conspicuous place in man's intellectual history": an education devoid of Euclid, Archimedes, Galileo and Newton was "illusory and worthless".[129]

For "progressive" studies, however, analytical topics should be admitted, but confined to Cartesian geometry, differential and integral calculus, differential equations, finite increments, definite integrals, and the calculus of variations. These should be supplemented by applications of mathematics, selected from mechanics, hydrostatics, the "mechanics of the Universe" according to Euler and Lagrange, and optics. He goes on to categorise various published works, many of them French, for use in advanced teaching. Surprisingly, given his supposed disregard of technology, he includes three on engineering applications, Poncelet's *Mécanique Industrielle*, Pambour's *Theory of the Steam Engine*, and his colleague R. Willis' *Principles of Mechanism.*[130]

Whewell paints a surprisingly rosy picture of the efficacy of college lectures, not supported by other evidence; and, like Peacock, he argues that the activities of private tutors should be confined to the poorest-prepared and dullest first-year students. He also expresses concern about the expense of private tuition, and the fact that private tutors, unlike college ones, had no responsibility to act as moral guardians. But, later, he urges that repression of private tuition must be "carried into effect with great caution and tenderness", in order not to "look with an unfriendly aspect upon a body of able, learned, and estimable men"; and he proposes a rather weaker measure that

[129] Whewell (1845), pp.41–43, 49, 60.

[130] Whewell (1845), pp.64–71, 200–203. Robert Willis was Cambridge's Jacksonian Professor of Natural Experimental Philosophy from 1837 to 1875. As well as an engineer, he was a noted historian of architecture: see Marsden (2004).

private tuition be forbidden only during the final six months of the degree course.[131]

Whewell objects to a call from the Oxford-educated geologist Charles Lyell, incongruously made in his *Travels in North America* (Lyell 1845), that a Royal Commission be sent to Oxford "as a counterpoise to the *vis inertiae* of the colleges." Doubtless aware that Cambridge would not escape if Oxford got such a Commission, Whewell claims that this would "be productive of immense harm." Late in the work, Whewell puts forward his most radical proposals: that there be created two new Tripos subjects, one for the "Progressive Sciences", as represented by the professors of anatomy, botany, chemistry, geology, and mineralogy, and another for "Moral and Intellectual Sciences".[132]

Later, Whewell published two supplementary volumes updating his work: these are *Part II: Discussions of Changes 1840–1850*, and *Part III: The Revised Statutes 1851–1852* (Whewell 1850, 1852). *Part II* recounts changes made in line with his recommendations, including alterations in the examining arrangements, formation of Boards of Studies, and the establishment of the new Triposes in Moral Sciences and Natural Sciences. He also makes some rather petty objections to Harvey Goodwin's recent textbook, *An Elementary Course of Mathematics* (Goodwin 1846); and he defends the veto powers of the Caput on the grounds that, though it could originate nothing, it provided a useful check on "rash voting" by the Senate.[133] His *Part III* concerns further changes to the statutes.

Whewell's *Liberal Education* was widely read and provoked varied responses, both critical and supportive. A.H. Wratislaw of Christ's College took issue with the central place that Whewell accorded to mathematics, arguing instead for the superiority of classics as a training for the mind. He claimed that Whewell's proposed syllabus showed how *little* mathematics was actually required for an honours degree:

> we must either burst with laughter, or weep for shame, at the portentous Sham, the miserable dwarf, which, to the exclusion of other things, has so long been arrogating to itself the title of a "Liberal Education" . . .; the Classical Tripos Education, narrow as is its present state, . . . is wideness itself as compared with the frightful narrowness of the Mathematical Tripos.[134]

131 Whewell (1845), pp.114, 139ff., 217, 222.

132 Whewell (1845), pp.127, 223–227.

133 Whewell (1850), pp.57, 82.

134 Wratislaw (1850), p.17.

Another who commented on how little mathematical knowledge was needed to gain a low honours degree as a Junior Optime was the young Harvey Goodwin, himself a Moderator for the Tripos.[135]

Sometimes, support took a form that Whewell would have deplored, as in a pamphlet from Alexander Bain, who drew attention to the need for *practical* knowledge of science:

> Let the prizeman in the scientific tripos get himself engaged in the workshop, the dockyard, the railway, the quarry, the farm, or the place of merchandise, and old difficulties will be perpetually transforming themselves into new facilities, and a college education become henceforth respected among the most practical minded of men.

But Bain's vision of technological utopia was far removed from Whewell's idea of the purposes of a Liberal Education. And, no doubt to Whewell's disgust, Bain advocated that inspectors be sent to *all* universities in Britain and Ireland, so that each might learn from the other: "In the present state of things, Cambridge might have been stationed on the inhospitable Caucasus, and Oxford protected by the black-feet Indians on the banks of the Missouri, for all that they have learned from the experiences of the other universities of their father-land."[136]

The 1850–1852 Royal Commission and After

The spirit of change that brought the Parliamentary Reform Bill of 1832 also inspired several attempts to rewrite the statutes of the University and colleges of Cambridge. As early as 1833, George Pryme, an active campaigner for granting degrees to Dissenters, requested that the Senate of the University set up a body to enquire into the value of the religious tests. But the then Vice-Chancellor, Joshua King, vetoed the proposal in Caput, and he did so again a

[135] Goodwin (1845). His criticisms are outlined more fully in Chapter 8.

[136] Bain (1848), pp.8, 24. The Trinity College Library copy of this pamphlet has a covering letter from Bain to Whewell "supporting to the best of my power, the Reforms that have been proposed in the curriculum. . . ." Two men named Alexander Bain, both Scottish, are listed in the *Oxford Dictionary of National Biography*. One was a London-based inventor who devised the first electrically driven clock; the other was an early psychologist influenced by John Stuart Mill, who had briefly been professor of mathematics and natural philosophy at Anderson's College in Glasgow and later was professor of logic at Aberdeen University. The latter is surely the author.

year later, when a similar proposal was made for medical degrees only. King supported a rival petition opposing the admission of "persons whose religious opinions are avowedly adverse to the tenets of the Established Church, and possibly opposed to the truth of Christianity itself", but this too was vetoed by another member of the Caput. King then set out the latter petition in Queens' College, of which he was President, in order to collect more signatures. Connop Thirlwall's enforced resignation from Trinity over the issue further inflamed the situation and polarised the University.[137]

In Parliament, a Bill for abrogation of religious tests for all degrees except divinity passed its third reading in the Commons but was defeated in the House of Lords on 1 August 1834. Then, following a change of Government, the Earl of Radnor revived the issue in the Lords but was defeated in June 1835. In April 1837, he tried but failed to have a commission of enquiry appointed to examine the statutes and revenues of Oxford and Cambridge Colleges. To remove ignorance and misconceptions revealed during the debate in Parliament, Benjamin Dann Walsh, a Trinity fellow, wrote *A Historical Account of the University of Cambridge, and Its Colleges; in a Letter to the Earl of Radnor*. As well as surveying the regulations, many of which had fallen into disuse, Walsh (in a precursor of Whewell's campaign) proposed the introduction of five new Tripos subjects, encompassing history, political economy, moral philosophy, the natural sciences and oriental and modern European languages.[138]

At last, in 1838, the University Senate set up its own committee to revise the University statutes; and Peacock doubtless had this committee in mind when he wrote his 1841 *Statutes*. Though one member was John Graham, the reform-minded Master of Christ's College, procrastination delayed its report until 1849 and its modest recommendations were mere simplifications of the *status quo*.[139] But matters were coming to a head: a year earlier, in July 1848, a petition signed by many leading scientists and Cambridge graduates was sent to the Prime Minister, Lord John Russell, suggesting the establishment of a Royal Commission to examine the University's affairs.

Many in Cambridge viewed this petition as an act of great treachery. Among the signatories were Charles Babbage, James Brewster, the brothers Charles and Erasmus Darwin, and nearly thirty other fellows of the Royal Society. Russell readily obliged, and Cambridge reacted with its own petition to the Chancellor, who was Queen Victoria's husband Prince Albert, claiming

---

137 Searby (1997), p.497.

138 Searby (1997), pp.500–504; Walsh (1837).

139 Searby (1997), pp.505, 506; Winstanley (1840), pp.196, 197.

that the Commission was "illegal and unconstitutional". This was signed by fourteen of the sixteen college heads, twelve professors and many members of Senate. Even would-be reformers were alarmed at the prospect of outside interference; and, in early 1849, the Senate took the precaution of setting up yet another syndicate to revise the statutes of the University.[140]

With justice, Prince Albert complained to Lord Russell that he had not received advance notice of the Royal Commission. The Queen, too, was displeased that the Commission had been set up in her name in so precipitate a manner. In her Diary, she noted that: "This is the way in which, I am sorry to say, the present Government seem always to spoil everything", and "the ferment about the Universities is quite dreadful."[141] Albert had already held discussions with the Vice-Chancellor, Henry Philpott (Master of St Catharine's and the first of Hopkins' senior wranglers), about his own ideas for extending the teaching of science; and he believed, perhaps naively, that reform might be accomplished internally.

In fact, the 1850 Royal Commission of Enquiry into Cambridge University was just part of an extensive review of education across the country: Oxford, the Scottish Universities, and the English public schools all had their commissions. The chairman of the Cambridge Royal Commission was John Graham (by then the Bishop of Chester), a member of the University committee that had recently reported on its statutes.[142] The other Commissioners were George Peacock, John F.W. Herschel, John Romilly and Adam Sedgwick: all were Cambridge graduates and both Peacock and Sedgwick currently held professorships there. Sedgwick was Woodwardian Professor of Geology from 1818 to 1872, and a close friend of William Hopkins. John Romilly, who graduated from Trinity in 1826, was a prominent Gray's Inn lawyer, liberal politician, and cousin of the Registrary, Joseph Romilly. John Herschel was a leading astronomer and an able mathematician.

Despite being so loaded with members with close Cambridge connections, the Commission's enquiries were resented as unwarranted interference. Many gave their evidence under protest. The Vice-Chancellor at that time was George Corrie, the Master of Jesus, a stanch Tory who, according to Adam Sedgwick, treated the Commission like "hostile invaders" and who was "timid and shy . . . singularly narrow-minded and . . . obstinate as a mule. . . . No

140 Searby (1997), p.521.

141 Quoted in Winstanley (1940), p.225n.

142 He had been fourth wrangler in 1816, then Master of Christ's College between 1830 and 1848, and Vice-Chancellor of the University in 1831 and 1840.

one . . . could have been less fitted to cope with the crisis confronting him."[143] William Webb, the Master of Clare, was equally uncooperative. So too was Benedict Chapman, the Master of Caius, who was reluctant to answer any of the questions asked, but did so "as a loyal subject of her Majesty . . . under a strong and earnest protest against the exercise of such power." Furthermore, Chapman refused to disclose financial information about college income and the value of fellowships and scholarships.[144]

Before the Commission reported, certain reforms were already made. These included King's College's surrender of the right of its students to proceed to the B.A. degree without examination; revision of the statutes of a few colleges; the establishment of a Board of Studies to oversee the Mathematical Tripos; the abandonment of the mathematical requirement for those taking the Classical Tripos; and the introduction of new Tripos subjects in Moral Sciences and Natural Sciences. The University could also claim that it had already initiated measures to revise its statutes. Many of these reforms had been driven by William Whewell (though he had opposed relaxing the restriction on the Classical Tripos), but Henry Philpott and Prince Albert also played important parts. Because of these, the Commissioners' Report was far less critical than it might otherwise have been.[145]

The *Commissioners' Report* (1852), hereinafter "*Rept.*" for short, is a mine of information about the University. All subjects taught and examined are described; and all professorships, lectureships and fellowships are listed, along with accounts of their foundation, statutes, duties and salaries. As well as expressing the Commissioners' own views, it summarises the often conflicting evidence that it received in response to its many questions, and it prints all this written evidence in full (the evidence on mathematics alone fills fifty-two pages). Many who gave evidence were openly critical of the *status quo*, but they disagreed on how best to change it.

In the end, the Report "was so conciliatory that the commission recovered much of their personal popularity."[146] In its "Conclusion", the Commissioners go out of their way to commend the University for its "willingness to enlarge the cycle of her Studies [by introducing new Tripos subjects], and to modify her institutions so far as the rigid severity of her laws permitted"; for its liberality in supporting financially "objects of great academical importance"; and for setting up a Committee to revise the University statutes. Likewise, the

---

143 Quoted in Winstanley (1940), pp.234, 235.

144 Venn (1898), v.3, p.139.

145 Fuller details are in Winstanley (1940), Ch.X, XI.

146 Clark (1895).

Colleges are commended for having "at great cost . . . enlarged their buildings, and . . . shown themselves careful guardians of their corporate property"; and some had "sought wholesome modifications of their Statutes, given up valueless or injurious privileges and . . . [removed] restrictions which prejudicially limited the free election to their Fellowships and Scholarships."[147]

But remaining problems were clearly identified. The Commissioners noted the shortage of suitable lecture rooms, laboratories and museums; it recommended the removal of individual rights of veto in the Caput; and it proposed that the Vice-Chancellor be helped in managing the University's finances by a Clerk of Accounts.[148] It challenged the University to make its education equally available to all, irrespective of religious belief; and, impressed by the efficacy of the new Board of Mathematical Studies, it recommended establishment of similar Boards in classics, theology, law, moral sciences, natural sciences and medicine. It also supported the creation of a General Council of Studies, accountable to Senate, to oversee all the instruction of the University. Though pleased that new Tripos subjects had been introduced, the Commissioners regretted the absence of facilities for the study of civil engineering and modern languages. They also criticised the deficiencies of the arrangements for students seeking only an ordinary degree.

The Report recommended to the University "an enlargement of its Professorial system—by the addition of such supplementary appliances . . . as may obviate the undue encroachments . . . of private tuition"; that new "branches of knowledge and professional pursuit" be made available for Academical Honours; and "the removal of all restrictions upon election to Fellowships and Scholarships." Though Fellows had in past times been hard-working teachers, "in modern times the Fellowships are frequently held by non-Residents [who] rarely contribute . . . to the course of Academical instruction, though their emoluments far exceed their original value." The Commission therefore thought it fair and reasonable that the Colleges be asked to contribute funds to the University "towards rendering the course of Public Teaching . . . more efficient and complete."[149] To achieve this, ten new professorships should be established in addition to the existing ones: one each in engineering, "descriptive geometry", anatomy, chemistry, zoology and Latin, and two each in divinity and law. Also, to perform the more elementary teaching, a large staff of University lecturers should be created.

---

147 *Rept.*, pp.201, 202.

148 The lack of any professional accounting of the University's finances at this time is quite astonishing.

149 *Rept.*, p.202.

In contrast with their quite radical suggestions for the University, the Commissioners were surprisingly uncritical of the individual colleges. They said nothing about the fellowship requirements of celibacy and ordination; and nothing about the extensive powers of college heads, though they suggested some improvements in the arrangements for appointing them. But their proposal that colleges should make financial contributions to the University was much resented.

The Commission's recommendations were not binding, and the hope was that some internal reform would satisfy the Government, so avoiding the appointment of an external Statutory Commission. Accordingly, the University's syndicate on revising the statutes was reconvened to consider how to respond to the Commissioners' Report, and two more syndicates were set up: one to consider "Public Professors and Public Lecturers" (known as the "Studies Syndicate"), another for lecture rooms and museums.

After much deliberation and disagreement, the Studies Syndicate reported in March 1854, making many proposals in line with the Commissioners' Report; but they had failed to find a way to create new professors and lecturers, as the colleges were unwilling to contribute. They need not have troubled, for, when put to Senate in May, their proposals were *all* rejected! Prince Albert was "astonished", and William Whewell remarked that the decision was "very little suited to give other persons a belief that we are fit to manage such matters for ourselves."[150]

As the Government had already set up a Statutory Commission for regulating Oxford University, it seemed only a matter of time before they would do so for Cambridge also. Accordingly, after the Oxford Bill became law, Henry Philpott, G. Ainslie of Pembroke and H.W. Cookson of Peterhouse, acting privately, drafted their own Bill for Cambridge, modified from the Oxford one in ways they thought desirable: this they sent to Prince Albert, who at once forwarded it to the Government. Philpott's role as an astute politician is plain: Lord Aberdeen assured the Prince that "Dr Philpott will be consulted in every stage of the proceeding, as the person, who from his moderate views, business habits and knowledge of the University, is best qualified to give the most valuable advice and assistance."[151]

With only slight modification, this was the Bill put before Parliament. Though this was withdrawn through lack of Parliamentary time, a similar Bill became law in July 1856. The Act set up the expected Statutory Commission to revise the statutes of the University and the colleges, and it also introduced some immediate changes, among them the replacement of the Caput by a

[150] Winstanley (1940), p.281.

[151] Winstanley (1940), p.283.

more representative Council, with more limitations on the power of the Vice-Chancellor and the removal of the power of veto by individual members. The Act also permitted graduation in all degrees, except those in divinity, without declaration of faith in the Thirty-Nine Articles. As first drafted, the Bill had still excluded Dissenters from membership of Senate, but this was removed in an amendment. But the colleges retained the right to exclude all but Anglicans from their fellowships if they so wished.[152]

The Statutory Commission to revise the statutes of the University and colleges was chaired by Henry Philpott and first met in September 1856. It gave the University and colleges until 1 January 1858 to draft their own proposals; failing which, the Commissioners would themselves do so. The task was a complex one, and there was much to-ing and fro-ing of drafts between the Commission, the Council and the Senate. Out-of-date statutes were rewritten and some significant changes made, mostly in line with the 1852 Commission Report, and largely with the cooperation of the University. Among the most significant, the University's Heresy Board was abolished, and academic officers were no longer required to swear conformity with the liturgy of the Church of England. Regarding mathematics, the ineffectual Sadlerian lectureships were abolished and replaced by a new Sadlerian Professorship of Pure Mathematics. Struggling to meet its deadline of the end of 1859, the Commission drafted in G.G. Stokes as an additional Secretary in February of that year.[153]

Later, in 1860, the Studies Syndicate addressed the unpopularity of the Moral Sciences and Natural Sciences Triposes. In their early years these attracted few candidates, and the former had the reputation of a soft option taken only by dullards. Their unpopularity was hardly surprising: passing the examinations in these Triposes did not then entitle a student to a degree, for Senate had turned down this logical proposal in 1854. The Senate's motive was apparently the wish to protect mathematics and classics from competition. At last, in the 1870s, the Studies Syndicate improved the arrangements for students taking an ordinary degree; and during the 1860s and 1870s most colleges decided to drop their requirements that fellows be unmarried.[154]

---

[152] In 1860, when James Stirling was senior wrangler far ahead of all rivals, he could not be elected to a Trinity fellowship, being a Presbyterian; and the next year's senior wrangler, the Methodist W.S. Aldis, suffered similarly: Winstanley (1947), pp.38, 39. Those Scots who were Trinity fellows, including Duncan Gregory and Archibald Smith, were either members of the Scottish Episcopal Church, or were sufficiently flexible in their religious beliefs to be able to satisfy the college's requirements.

[153] Winstanley (1940), pp.314–338; Wilson (1990), lett. 170.

[154] Winstanley (1947).

More momentous and contentious was the Religious Tests Act of 1871 that applied to the Universities of Cambridge, Oxford and Durham. This finally abolished the requirement that fellows subscribe to the Anglican faith, and that heads of colleges need be ordained. This Act had been hotly contested, with petitions on either side from Cambridge, strong lobbying from Dissenters, and much concern that abolition would mortally weaken the Church of England. Some feared that access to influential positions in the universities would be gained not only by Dissenters, but by infidels who were "enemies of Christianity".[155]

In 1877, Parliament again became involved, passing the Oxford and Cambridge Universities Bill that set up further Statutory Commissions and invited the universities and colleges to introduce more reforms. The Cambridge Commissioners included Philpott, Stokes and G.W. Hemming (1st, 1844)—all three former pupils of Hopkins who had been senior wranglers. Perhaps the major change was an annual levy on all colleges, paid to the University, the amounts being proportional to their respective sizes and wealth. This levy helped to fund an expansion of centralised teaching, and the creation of new University posts. Gradually, the teaching of the University was evolving into a more sensible system.[156]

Commission Evidence on Mathematics

Regarding Mathematics, the 1850 Commission asked for responses to thirteen questions. We concentrate on just two: the place of analysis and the role of private tutors.

Question 9 asked whether "the course of Mathematical study . . . is tending to become more and more exclusively analytical and symbolic?" Though the "continental" calculus was by now well established, there was still debate over the right balance between geometry and analysis. Though some respondents favoured a return to traditional geometrical methods, the weight of opinion was that the balance was about right, and that the amount of geometry had actually increased somewhat in recent years. However, the Commission had its own reservations, for it recommended that, in "Mixed" (i.e. Applied) Mathematics, "all unnecessary exuberance of an analytical calculation be repressed." And it approvingly reported that, after a period where analytical methods had been in the ascendancy, "the inconvenience of an undue tendency to

[155] Winstanley (1947), Ch.3.

[156] Winstanley (1947), Ch.3, 5, 7, 8.

analytical processes and the dexterous use of symbols to the neglect of natural relations has been perceived and is in course of correction."[157]

The Commission's Question 11, on the place of private tutors, now seems loaded in their favour:

> What is the course usually followed by Students in preparing themselves for the examinations for Honours? Is not the assistance of a private Tutor, with very rare exceptions, considered indispensible? Are not many of the private Tutors men of great eminence, who devote themselves to the private instruction of Students as a professional pursuit? Can you suggest any changes to this system, by which the labours of this important body of teachers might be rendered more generally useful to the students, without increasing unduly the expenses of academical education?[158]

Of the sixteen mathematicians who responded, fifteen were then, or had recently been, college fellows or tutors; of these, three were Masters of colleges, and one, G.G. Stokes, was Lucasian Professor. The exception without any college affiliation was William Hopkins, identified as "President, Geological Society" rather than as the leading private tutor. At least five of the other fifteen respondents were former pupils of Hopkins: Stokes, Philpott, Mould, Goodwin and Ellis. All admitted that the present system was unsatisfactory since it was impossible for college tutors to cope with the disparate abilities of their charges.

Many others responded similarly regarding college tuition in general: Charles Merivale, a Latinist and classical historian of St John's College, even suggested that College tuition "might be abolished altogether, and the Students be left to private assistance, guided by College Examinations, and placed under some College or University Regulations."[159] Among the mathematicians, only William Whewell, Master of Trinity, and Henry Philpott, Master of St Catharine's Hall, were antagonistic to the role of private tutors. Though most of the others remarked on the large financial burden on students, they regarded private tutors as indispensible, and sometimes "men of great eminence".

As well as the expense, Whewell objected to "the enervating effects produced upon the mind by an excessive reliance upon the aids afforded by Private Tutors . . . for the dependence on private Tutors enfeebles the mind,

157 *Rept.*, p.112.

158 *Rept.*, p.221.

159 *Rept.*, p.77.

and depraves the habits of study." Nor did he admit the tutors' eminence in mathematics:

> Many of the Private Tutors are good mathematicians in the kind of mathematics which is generated and kept up by the prevalence of the system of private tuition; but many of these would not be found good mathematicians in any other field for the application of mathematical knowledge.

Some private tutors might be engaged as college lecturers, as already happened in some colleges; but Whewell believed that this would not improve matters as long as private tuition was permitted. Yet he argued that if college lectures were modified to supersede private tuition, they would thereby not be improved, but *spoiled*. He thought it impossible to modify the examinations so as to eliminate the worst sort of private tuition, given that the examiners were usually also private tutors.[160]

Philpott's reply was more moderate. He observed that students may fail to achieve high honours despite continued private tuition, and that high honours had sometimes been gained by students who received little or none.[161] Though private tuition could be advantageous when both tutor and student were well motivated, it was injurious when the tutor attempted to supply "ready scraps of information", instead of encouraging the pupil to exert his own mind.[162]

William Hopkins' own ten and a half pages of evidence covers all aspects of the mathematical instruction and examinations. He remarks, as did others, on the successive changes which had taken place between 1827 and 1850, and which are outlined in the following section. Shortly before 1827, there had been a substantial increase in candidates for Mathematical honours, and important extensions in what was taught, mainly through the influence of G.B. Airy's lectures as Lucasian Professor, and by the publication of his *Mathematical Tracts*. Hopkins considers the various changes in the examination system to have been essential and important improvements. But he regrets the disappearance of *viva voce* examinations, and he advocates their reintroduction as "the surest test of that higher intellectual power, which enables a man to take comprehensive and philosophical views of mathematical and

---

160 *Rept.*, pp.74, 273, 275.

161 In fact, there were few students in the latter category by this time; but George Green, J.J. Sylvester and J.C. Adams received less instruction than most.

162 *Rept.*, pp.76, 264.

physical science, and prepares him to grapple with its higher difficulties." Allied with the written papers, these would provide a more reliable way of placing the higher candidates in order of merit. But Hopkins thought highly of the present [1850] system, as conducive to "exactness of thought and perspicuity of language."[163]

He gives a clear summary of the role of private tutors, observing that candidates for mathematical honours usually study with them for the latter two-thirds of their time at University and including the last long vacation. There were in the University

> four or five men of high mathematical attainments, who . . . have devoted themselves to private tuition as a profession. To these may be added a few others who, as resident Fellows of Colleges, have also devoted their time to private tuition in the higher branches of mathematics. . . . Most of these men have obtained the highest academic honours, and several have been the authors of mathematical treatises and original memoirs. Nearly the whole of the higher mathematical tuition has devolved upon them, and I may venture to assert that no men in the University have performed their duties with more zeal and earnestness than themselves. There are also many others who receive a few Mathematical Pupils, but not such as usually obtain the higher mathematical honours.

He felt that the best private tutors should in some way be recognised as authorised teachers; but he shared Whewell's view that an increase in the number of official College Lecturers would be ineffective. A better way would be to create a class of Public Lecturers, associated with the University professors rather than the college tutors. However, he rightly foresaw that such a proposal would encounter great difficulties, for it would weaken collegiate independence which "seems also to be interwoven . . . in our affections."[164]

Hopkins then pertinently asks "Why have not the present Mathematical Professors attempted to establish some system of Academic Lectures like that above suggested?" And he gives his own answers: that the collegiate system pervades the institution; that the Plumian Professor (James Challis) has little time because of his responsibilities for the Cambridge Observatory; that successive Lowndean Professors (then George Peacock, a member of the Commission) had normally been non-resident throughout the century; and that

---

[163] *Rept.*, pp.239, 242, 243.

[164] *Rept.*, pp.245, 246.

the Lucasian Professor (the recently appointed G.G. Stokes), though then resident, was under no obligation to be so. Though the Professors were obliged by statute to give some advanced lectures on their specialisms, "The University has never imposed upon them the duty of giving such [Academic instructional] lectures, and many persons would probably regard them as stepping beyond their proper line of duty if they were to make the attempt."[165]

He estimated the expense of private tuition for the higher students at around £150 over the whole three years, including £60 for two summer vacations. If more effective *public* tuition were to be introduced at say £4 per term, or £36 pounds over three years, then students who still used a private tutor during two long vacations might save about £20 per year.[166]

Hopkins concludes his evidence with a discussion of the general character of the higher students. The test of merit provided by the Mathematical Tripos examinations is strictly intellectual, and was used as such by the Colleges in their appointments to Fellowships. But he asks "How far can this intellectual test be depended upon as a test of high moral conduct?" Hopkins believed it to be "unquestionably the best moral test that could be acted on", citing the unexceptionable moral character of almost all the students who had taken distinguished degrees under his guidance.[167] For Hopkins, mathematics provided not only the best *intellectual* training that a young man could have, but the best *moral* training too.

The Commission evidence supports Charles Bristed's student view of the close relationship between private tutor and student. Bristed wrote that:

> The intercourse between the private tutor and his pupil varies of course according to the character and age of both parties, but it is usually of the most familiar kind, the former seldom attempting to come Don over the latter. When they are personal friends, as is not unfrequently the case, it becomes very free and easy, sometimes blending amusement with instruction in a rather comical way.

This he contrasts with college teaching:

> The present staff of College Lecturers could not, except in some few of the smaller Colleges, supply the demand for instruction [if there were no

[165] *Rept.*, pp.246, 247.

[166] *Rept.*, p.247.

[167] *Rept.*, pp.248, 249.

> private tutors]. . . . Nor, even were they . . . increased, could any public lecturer have the intimate knowledge of his pupils' acquirements, deficiencies, capacities, and wants, that the private tutor has, nor would he be likely to take so strong a personal interest in each individual of them.

And he emphasises the good work done with private tutors during the vacations. Bristed also notes the uneasy relationship between college fellows and the most successful private tutors:

> It certainly must be annoying to a College Don that a man who has perhaps taken a lower degree than himself, and has no legal or formal place in the University, should yet enjoy a larger income and a greater local reputation in addition to the comforts of a family. [168]

Whewell's stated concern that private tutors, unlike college tutors, had no responsibility as moral guardians, may have been valid in principle; but he seems out of touch with, or is deliberately ignoring, the realities of the situation.

The Commissioners' Report reviews the evidence submitted on the historical development of the Tripos, noting the total lack of regulation of examiners before the 1848 Board of Mathematical Studies was set up. Though "it is owing probably to this absence of regulation . . . that so much was effected" in introducing new mathematical subjects, this previous "somewhat paroxysmal state of progress" was now under the Board's control.[169]

The Commissioners agreed that the system of College Lectures was defective, and had given rise to the growth of private tuition. They saw clear advantages in introducing an organised system of University lectures with open classes, that would go some way towards diminishing reliance on private tutors, but would necessitate the appointment of several Public Lecturers. It noted the increasingly rigorous nature of the Examinations, not only for students, but for Examiners who had to devote "many hours of the night" to marking the scripts within the required time. It also criticised the excess of bookwork in the Examinations that led inevitably to the evils of "cramming". And it favoured restoring a *viva voce* examination, if not for all students, then for those who had performed nearly equally in the written Examinations.[170]

---

[168] Bristed (1852), v.1, pp.206, 212, 213.

[169] *Rept.*, pp.106, 107.

[170] *Rept.*, pp.88, 108, 110–112.

The Commissioners seem to go out of their way to be complimentary to William Hopkins. Together with William Whewell's, his evidence is that most extensively quoted. He is rightly described as "one excellently qualified to form an opinion" on teaching methods; and, "an authority entitled to every consideration" regarding *viva voce* examinations.[171]

The Tripos and Smith's Prize Examinations

The word Tripos originates from very early times. In the fifteenth century, degree candidates appeared before a University representative who was seated upon a three-legged stool (Latin *tripus*), and who engaged them in oral debate in Latin.[172] From these oral examinations came the term "wrangler", meaning one who could wrangle or argue effectively. Though written papers were eventually introduced, a *viva voce* Latin disputation continued into the mid-nineteenth century. But by then it had degenerated into a pre-rehearsed farce, since most candidates' ability to speak Latin had become vestigial. Finally, the moderators of 1840, T. Gaskin and J. Bowstead, took the law into their own hands and discontinued it.[173] It was these *viva voce* examinations that both Hopkins and Whewell wished to restore, but in English rather than Latin.

From 1747 until 1824, when the Classical Tripos began, the ranking of candidates in the Mathematical Tripos as Wranglers, Senior and Junior Optimes remained the sole official measure of a graduate's achievement. Large numbers obtained only Pass, or Poll, degrees, and quite a few failed to graduate at all. The Old Etonians of King's College, for long exempt from taking the Mathematical Tripos, had no opportunity of obtaining honours. Whether any *could* have done so is another matter: the 1864 *Report of Her Majesty's Commissioners on Certain Colleges and Schools* noted that before 1836 there was apparently no mathematical teaching of any kind at Eton, and that mathemat-

---

171 *Rept.*, pp.106, 110.

172 The history of the word "Tripos" is described in full by Rouse Ball (1889), pp.217–219. It is enough to reproduce his quotation from Christopher Wordsworth's *University Society in the Eighteenth Century*, that the word underwent successive changes of meaning "from a thing of wood to a man, from a man to a speech, from a speech to two sets of verses, from verses to a sheet of coarse foolscap paper, from a paper to a list of names, and from a list of names to a system of examination": Wordsworth (1874), p.21.

173 Rouse Ball (1889), Ch.9. Gaskin and Bowstead were second wranglers in 1831 and 1833 respectively, and Bowstead had been a pupil of Hopkins.

ics was first made compulsory at Harrow in 1837.[174] It was undoubtedly the poor standard of mathematics in the public schools that caused Cambridge to resist for so long the introduction of entrance examinations, which might have excluded many of their pupils.[175]

Major changes to the Tripos examinations had been introduced in 1824 and 1828, extending the written papers to twenty-three hours (seven assigned to problem-solving), taken over four days. The first two days were devoted to the more elementary topics and simpler applications. But candidates were first placed into classes or "brackets" on the basis of earlier preliminary examinations, and each class took separate examinations according to ability. From 1833, the examinations stretched to five days, with twenty hours assigned to "bookwork" and seven-and-a-half to "problems". For the first four days, all candidates took the same examinations: only on the fifth day were they split into classes.[176]

Inexorably, in 1839, the examination period was further extended to thirty-three hours (eight-and-a-half for "problems"), taken over a whole week; and in 1848 to forty-four-and-a-half hours (twelve for "problems"), taken over eight days, but with a break of a few days after the third. In this last form, which went unaltered until 1873, the examiners issued a list after the first three days of those candidates deserving of honours in mathematics; and only those candidates competed during the following five days.

In his evidence to the Royal Commission, G.G. Stokes summarised the examination statistics for the few years previous to 1850. Approximately 150 students per year took the examinations for mathematical honours, but around one fourth or one fifth of them failed to reach the required standard. In all, only about 38% of all B.A. graduates obtained honours, the remainder getting ordinary "poll" degrees. About one sixth of all B.A. candidates were rejected outright. Stokes estimated that the lowest student on the honours list obtained about one fourth or one fifth of the average marks obtained by the few best students. In fact, the huge gap between top and bottom marks was frequently wider, and remained so into the future.

Two new regulations had enabled students who failed honours to obtain ordinary degrees, and permitted students to proceed to the Classical Tripos without obtaining Mathematical honours. Stokes observed that these "rendered it so much less severe a measure than formerly to refuse a Student a

---

174 See Dubbey (1978), p.14. But Harrow presumably offered voluntary mathematical instruction, for A. Ellice was a pupil there and became senior wrangler in 1833.

175 Winstanley (1947), pp.146, 147.

176 Rouse Ball (1889), pp.211–213.

place on the Mathematical Tripos that latterly the standard seems to have been somewhat raised"—a comment that suggests that the examiners had often felt under pressure to be lenient.[177] Stokes' figures imply that nearly 300 graduated each year with a B.A. degree, that 110 to 120 of these gained honours of some sort, and that more than 50 failed outright. The last number is surely not unconnected with the many tales of drunkenness and dissipation among the "poll men".[178]

The Tripos order-of-merit lists survived until 1909, when replaced by broad classification as 1st-, 2nd- and 3rd-class honours. The last on the list of Junior Optimes was nicknamed the "Wooden Spoon". There was usually much unofficial hilarity, and official disapproval, at graduation ceremonies, when friends of the "Wooden Spoon" lowered a huge spoon from the balcony as he was leaving the hall, and then led him in procession clutching his trophy.[179]

The commitment of examiners and moderators did not always match that shown by the best candidates. In the early decades of the nineteenth century, the students' papers were informally, even negligently, assessed. Only after 1827 were all the examination papers printed beforehand; and the Tripos of 1836 is said to have been the first in which all the papers were marked: previously, the examiners "had partly relied on the impression of the answers given"![180] But as the century progressed, the examinations became more rigorous and the assessment more professional.

The "bookwork" of the Tripos Examinations largely consisted of reproducing, as quickly and concisely as possible, theorems and proofs which had been carefully memorised beforehand. The "problems" would have required more ingenuity, but many were of a standard sort similar to those of past papers, and which the private tutors would have predicted.

Before 1848, when the Board of Mathematical Studies was first set up, there was no set syllabus: topics covered in the examinations were determined by past precedent and by the individual moderators and examiners. Tutors and students alike would have relied heavily on past papers, which were

---

177 *Rept.* p.267a.

178 A table of six sets of degree results at ten-yearly intervals given by T. Gaskin is broadly in line with Stokes' figures (*Rept.* p.227).

179 A photograph of the last Wooden Spoon procession of 1909 is reproduced in Warwick (2003), p.210. The gigantic decorated spoon, with handle made from an oar, still survives: Stewart (2002), p.4.

180 Rouse Ball (1889), pp.212, 213, whose authority was Samuel Earnshaw, senior moderator for that year and senior wrangler in 1831.

available in published form, and experienced tutors knew the likely preferences of individual examiners. But the Board exerted control from then on, recommending which topics should and should not be covered. For example, their first report, of 1849, recommended that:

> Questions from the theories of Electricity, Magnetism, and Heat, had been introduced into the Examination, but so sparingly, that it was doubtful whether the subjects were to be considered as forming part of the regular course or not. Accordingly, the Board . . . recommended that these subjects be not admitted into the examination.[181]

It is ironic that, in the very next year, the young James Clerk Maxwell enrolled at Cambridge after studying at Edinburgh University: for he was later single-handedly to revolutionise the mathematical theories of all three of these deleted subjects.[182]

In contrast with the *laissez faire* procedures of earlier times, the Board took an active interest in vetting the questions proposed by the moderators. The experience of C.F. Mackenzie, a moderator in 1853–54, is recounted by his friend and biographer Harvey Goodwin:

> He expressed much good-humoured surprise at the trouble which the preparation of questions for the Examinations cost him. The practice in Cambridge, and it is a very wholesome one, is for each Examiner to submit to the whole Board each question which he intends to propose to the Candidates for Mathematical Honours: and each member of the Board, when a question has been read, makes it his business to criticise it with the utmost severity.. . . Mackenzie had not prepared his questions with the prospect of so severe a test; and I remember well the good-humoured regret with which, after much discussion and hearing a variety of objections, he finally abandoned several of his questions.[183]

To be ranked as one of the top wranglers provided a near-guarantee of election to a college fellowship, and opened many doors to a successful career.

---

[181] Reprinted in *Rept.* p.267b.

[182] One of Hopkins' star pupils, Maxwell was second wrangler in 1854 behind E.J. Routh. When, in 1860, Routh himself became a moderator along with H.W. Watson (2nd, 1850), these two published their examination papers along with model solutions, as a guide for students: Routh & Watson (1860).

[183] Goodwin (1864), pp.52–3.

Nevertheless, some able mathematicians took a "poll" degree. In earlier times, Charles Babbage was prevented from sitting the written papers of the 1813 Tripos when the examiner failed his Latin *viva voce* thesis for heresy: it has been suggested that Babbage did this deliberately, having no interest in coming second and knowing that he could not beat John Herschel. And Babbage and Herschel's "Analytical Society" colleague, Edward ffrench Bromhead, did not take the examinations, content to adopt the independent lifestyle of a wealthy country gentleman.

But competition for a top Tripos place was severe and not a few students buckled under the strain. Francis Galton was a promising mathematician who had been a pupil of Hopkins, but who suffered a breakdown because of overwork and took a poll degree.[184] Others, too, succumbed to physical and mental stresses in the run-up to the Tripos examinations. Charles Bristed suffered a physical breakdown from which he recovered just in time to prepare for the final examinations. He only just qualified to take the Classical Tripos examinations by struggling to third-last place among the Junior Optimes of the 1845 Mathematical Tripos; but he came high among the second class of honours in Classics.

Bristed described his own and several other student breakdowns. Having applied himself diligently to "the much execrated Mathematics", he placed some small bets that he would "pass *high* among the Junior Optimes." But about ten days before the examination, "there came upon me a feeling of utter disgust and weariness, muddle-headedness, and want of mental elasticity. I fell to playing billiards and whist in very desperation, and gave myself up to what might happen." Meanwhile, another Trinity scholar who stood a much better chance than himself "gave up from mere 'funk', and resolved to go out in the Poll." Bristed believed that he gained a low Junior Optime place only because the original examiners took ill, and were replaced by his good friend, R.L. Ellis, and his own private tutor![185]

Bristed also describes how C.T. Simpson, the second wrangler in 1842, had previously worked twenty hours a day for a whole week before a College examination; but during the Tripos he "almost broke down from over exertion . . . and found himself actually obliged to carry a supply of ether and other stimulants into the examination in case of accidents." And he reports, rather unsympathetically, a "singular case of *funk*" in 1843, when "the man who would have been second . . . took flight when four of the six days were over, and fairly ran away—not only from the examination but out of

184 See also Chapter 5, p.108.

185 Bristed (1852), v.1, pp.313, 314.

Cambridge, and who was not discovered by his friends or family till some time after. As it was, he came out ninth in the list of Wranglers."[186]

Though Bristed never gives names, this is easily identifiable as Goodeve of St John's: he returned in time to take the Smith's Prize examinations, but was beaten into third place by J.C. Adams and B. Gray.

Another who under-performed was Henry Fawcett. A student of Hopkins and tipped to become senior wrangler in 1856, he was affected by nerves and insomnia and slipped to seventh place. Despite later being blinded in a shooting accident at the age of 25, Fawcett served as Cambridge's Professor of Political Economy during 1863–84, and he was an active Member of Parliament. His wife was the redoubtable suffragette Millicent Garrett Fawcett, and sister of Elizabeth Garrett Anderson, Britain's first licenced woman doctor.

One of the most dramatic cases was James Wilson, senior wrangler in 1859, who was coached by Stephen Parkinson. He suffered a nervous breakdown immediately after the examinations, and on recovery found that he had forgotten *all* his mathematics apart from elementary algebra and Euclid. But he still managed to make a career as a mathematics teacher.[187] The saddest case of all was James Savage, senior wrangler in 1855, who three months later was found dead in a ditch: he was said to have been "botanising" and died of "apoplexy".[188] Another who suffered a serious illness, some two or three years after becoming senior wrangler in 1850, was William H. Besant.[189]

Illness and early death (often from consumption) were more common in the mid-nineteenth century than today; and sometimes, as today, death was accelerated by destructive lifestyles. An example of the latter was Richard Stevenson (3rd, 1834), elected to a Trinity fellowship in 1835 and dead of consumption two years later aged only 25, following alcoholism and "descent into madness".[190] In addition to the cases just mentioned, W.J. Steele (2nd, 1852)

---

186 Bristed (1852), v.1, pp.131, 173.

187 Howson (1982), pp.125, 126.

188 Whether Savage's earlier exertions had played a part is unknown; Romilly also records that Savage "had been annoyed at not being elected Fellow" of St John's. His brother, T. Savage of Pembroke College, was second wrangler in 1857: Venn (1940); Bury & Pickles (2000), pp.269, 203. A later high wrangler who survived for just a few months after the Tripos was Andrew Craik (4th, 1874): before admission to Emmanuel College, he had been a top student at Aberdeen.

189 Besant (1902), p.72. Comments of several other students on the demands of the system are described in Chapter 5, pp.108, 109.

190 Smith & Stray (2003), p.82.

died at 23, A. Ellice (1st, 1833) and G.M. Slesser (1st, 1858) at 28, D.F. Gregory (5th, 1837) and H. Goulburn (2nd, 1835) at 30, C.J. Newbery (3rd, 1853) at 31, R.B. Batty (2nd, 1853) and A.V. Hadley (1st, 1856) at 32.

Some who gained top places had suffered crises at an earlier stage. Among them was James Clerk Maxwell, who fell ill in June 1853, the summer before his Tripos examinations, probably from overwork and nervous exhaustion, and had to be cared for by his friends, the Reverend and Mrs C.B. Tayler, whom he was visiting. Maxwell had for long gone his own way, reading far beyond the prescribed work. But, for some time after his illness, and under Hopkins' direction, he was able only for a lightened load. By November, Maxwell assured his cousin Miss Cay that:

> I am in a regular state of health though not a very regular state of reading, for I hold it is a pernicious practice to read when one is not inclined for it. So I read occasionally for a week and then miss a few days, always remembering to do whatsoever College and Hopkins prescribe to be done, and avoiding anything more.[191]

Also deserving sympathy were those students with little or no mathematical aptitude who, before 1850, had no option but to study the subject. But the talents of some of the mathematically deficient were sometimes recognised. Among the most successful was the writer and politician Thomas Babington Macaulay (1800–59), who entered Trinity College in 1818. Though a literary prodigy, he found mathematics abhorrent and attained only a "poll" degree; yet he was elected to a Trinity fellowship in 1824 on the strength of his performance in the Trinity fellowship examination, which was not exclusively devoted to mathematics. Another who cared little for mathematics and aimed only for a "poll" degree from the outset was the biologist Charles Darwin.

Whereas the Tripos questions put a high premium on memory and speed, the examination questions for the Smith's Prizes were far more challenging and often open-ended. Robert Smith (1689–1768) had been Plumian Professor and Master of Trinity College, and left a bequest founding the prizes for proficiency in mathematics and natural philosophy. Only a few top candidates competed for these honorific prizes, taking special papers immediately after the Tripos examinations. Unlike the Tripos papers, the Smith's Prize papers were usually set by the professors, and the examinations held in their homes. These examinations played a considerable part in establishing the Cambridge

[191] Campbell & Garnett (1884), pp.134–139.

emphasis on *applications* of mathematics. They continued from 1769 until 1883; and were replaced, from 1885, by the Smith's Prize essay competition which still continues.[192]

Inevitably, top wranglers won the Smith's Prizes; but the order of merit in the Tripos was often reversed for the Smith's Prizes.[193] Perhaps the most notable case was that of 1845, when William Thomson was unexpectedly placed second in the Tripos, behind Stephen Parkinson of St John's. But Thomson easily won the first Smith's Prize. Robert L. Ellis is said to have commented to his fellow-examiner Harvey Goodwin that: "You and I are just about fit to mend his [Thomson's] pens"; while William Whewell informed J.D. Forbes that "Thomson of Glasgow is much the greatest mathematical genius: the Senior Wrangler was better drilled."[194]

In later times, new Tripos regulations were introduced in 1882 and 1886, dividing it into three Parts. An advanced Part III was taken later by just a few candidates; and the degree classification was based only on Parts I and II. The first woman to appear on the honours lists of the *Cambridge University Calendar* was a Miss Burstall of Girton College, who in 1882 was equal to the last of the Senior Optimes. But she was not the first to complete the Tripos: a few others did so in 1880–81 though they were not allowed to graduate. The most illustrious were Charlotte Angas Scott, who merited the eighth wrangler's place in 1880, and Hertha Marks who completed the Tripos a year later. Scott obtained a doctorate in algebraic geometry supervised by Arthur Cayley, and became the first head of mathematics at Bryn Mawr College in Pennsylvania. Marks became the second wife of the electrical engineer William Edward Ayrton, and collaborated with him on electrical researches.[195]

From 1882 on, women graduates were listed separately from the men, but with their notional place on the men's table indicated. In 1890, Philippa Fawcett of Newnham attained the unique distinction of being listed "above the Senior Wrangler". She was the only child of Henry Fawcett and Millicent Garrett Fawcett and was tutored by Ernest Hobson, who later became

---

[192] Barrow-Green (1999).

[193] A rare exception was Robert Kalley Miller, a Glasgow M.A. unlisted in the 1867 Tripos and awarded an *aegrotat* degree: he recovered in time to gain the first Smith's Prize.

[194] Smith & Wise (1989), p.80; Thompson (1910), v.1, pp.97, 98, 103.

[195] Further information on Scott, Marks and many other mathematicians is given in *Oxford DNB* and the St Andrews University *MacTutor History of Mathematics* website (www-history.mcs.st-andrews.ac.uk/history). Other early women graduates in Britain are listed at the Davis Archive for female mathematicians (www-history.mcs.st-andrews.ac.uk/history/Davis/index.html).

Sadlerian Professor of Pure Mathematics. In view of the extra costs involved, few female students would have received the intensive private tuition necessary to gain a high Tripos place. But the Fawcetts had a political point to make about the capabilities of women, and their daughter had the talent to oblige.

5.
William Hopkins

Biography

William Hopkins was born at Kingston-on-Soar, Derbyshire on 2 February 1793, the son of a gentleman farmer. His early education was desultory and designed to train him in farming. His father gave him a small estate near Bury St Edmunds in Suffolk, but William found its management unrewarding and uncongenial. After the early death of his first wife, a Miss Braithwaite, he sold the estate and, aged nearly thirty, entered St Peter's College (Peterhouse), Cambridge in 1822 as an undergraduate. In 1827, he was placed seventh wrangler, in the same class as Augustus De Morgan (who came fourth), later London University's first professor of mathematics.

While still a student, Hopkins married his second wife, Caroline Frances Boys (by whom he later had a son and three daughters), and so he could not be elected to a Fellowship; but he was promptly appointed a mathematical lecturer of St Peter's College, and also Esquire Bedell to the University. The duties of this latter post included carrying a ceremonial mace when accompanying the Vice-Chancellor on public occasions, and carving the joint for him at official dinners. Hopkins held this position from 1827 until his death in 1866, receiving an annual salary and gratuities amounting to more than £100. Henry Gunning, a previous Esquire Bedell, thought highly of the new appointee's respectability, if not that of some former holders of the office, "men whom I blush to recollect as my colleagues." And the announcement of Hopkins' death in *The Times* newspaper stated that: "The office [Esquire Bedell] which Mr Hopkins filled in the University was one on which he conferred more dignity than it gave to him."[196]

Among his duties, Hopkins was responsible for ensuring that arcane social rules and privileges were adhered to on formal occasions. As one example, in December 1855 he had to consult the Registrary, Joseph Romilly, about a difficult case: whether, during services in Great St Mary's Church, a certain

---

196 Stokes (1911), p.118; Gunning (1854), v.2, pp.358, 359; Anon. (1866).

nobleman who had been an undergraduate was entitled to sit in a gallery known as Golgotha, along with heads of colleges and professors. Romilly ruled in the negative, because the nobleman in question, being a younger son, had not been entered as a nobleman when he first came to university.[197]

On Friday 12 December 1834, Hopkins accompanied Joseph Romilly on a cold six-and-a-half-hour carriage journey to the home of the Marquess Camden to appoint him as the new Chancellor of the University. The next day, a thirty-seven-strong deputation of College heads, M.A.s and University Officers processed behind the mace-bearing Bedells to perform the Installation. On returning to Cambridge at 10p.m., Romilly and some others "ate a pheasant at [Henry] Philpott's: [but] Hopkins like a good husband went home at once."

In March 1842, Romilly and Hopkins were members of a Cambridge University deputation to Buckingham Palace to congratulate Queen Victoria on the birth of the Prince of Wales. (But the time of the audience had been advanced at short notice, and a chagrined William Whewell arrived too late, just as the guard was marching off.) On 25 March 1847, Hopkins and Romilly again visited the palace, this time to appoint Prince Albert as Chancellor.[198]

But Hopkins' duties as Esquire Bedell were only a small part of his activities. Soon after his own graduation, he quickly built up a formidable reputation as a successful private tutor. He devoted many hours a day to teaching and to preparation for teaching; and this, along with his Bedell's salary, provided a very satisfactory income. Hopkins remarked that an outstanding coach could make £700–800 during the academic year, and even more if he coached in the long vacation, charging about 10 guineas per student; and he himself certainly earned even more. Though private tutors could earn a large amount, more than most professors, none except Hopkins could have approached the £1854 which the Professor of Divinity received in 1850.[199]

---

197 Bury & Pickles (2000), p.222.

198 Bury & Pickles (2000) p.222; Bury (1967) pp.64, 234, 235; Bury & Pickles (1994) p.203.

199 Hopkins' evidence in *Commissioners' Rept.* 1852, p.247, states that: "The expense of private tuition to most of our students of the higher class probably amounts on the average to about 150*l.* during the three years of their Undergraduateship. This sum includes 60*l.* usually paid during two of their summer vacations." Thus three concurrent classes of five students in each of the three years of study would give an income of 750 pounds p.a. Some tutors may have taught more students than this and some fewer. Hopkins (1854), discussed below, further addresses the cost of teaching.

In his influential study of Cambridge University, Sheldon Rothblatt (1968, p.201n) commented that the tutors' income "was an extraordinary amount, almost within the definition of an upper middle class income [around £900 p.a. in 1851]. If coaching were combined with a fellowship or college lectureship [or, in Hopkins' case, the post of Esquire Bedell], the total emoluments . . . might equal the income of the Lady Margaret's Professor of Divinity, the most highly endowed chair in Cambridge [of £1085 p.a. in 1885 and possibly more earlier]."

In 1838, Hopkins had high hopes of succeeding the absentee Charles Babbage as the Lucasian Professor of mathematics, but these were dashed by the appointment of Joshua King, then the President of Queens' College. Hopkins alludes to this in a letter to J.D. Forbes (written some years before their relationship was strained by scientific disagreements):

> You are doubtless aware of Babbage's resignation of his professorship. Earnshaw and myself first started as candidates. I held myself *perfectly safe* till the Head of a College presented himself as a candidate to his brother Heads who are the only electors. This is King the President of Queens who will doubtless be elected though physically disqualified by paralysis from performing any of the more important duties of the professorship. I doubt however his holding it long.[200]

King was duly appointed despite his disabilities; he held the chair until 1849, and he lived on until 1857. His eventual successor was not Hopkins, but Hopkins' former pupil G.G. Stokes.

A year earlier, on 11 February 1838, Hopkins had written another, rather strange, letter to Forbes, in support of Philip Kelland's candidacy for the Chair of Mathematics at Edinburgh. Hopkins had already supplied for his former pupil a warm testimonial, which, significantly, is printed first among Kelland's other testimonials from many leading academic figures.[201]

In his letter, Hopkins reiterates his support for Kelland in warm terms, concluding that "there appears to me to be no young man of the present day whose claims (as far as they rest on talents & acquirements) can be considered so well established as his. . . ." Then he alludes to the rival candidacy of Duncan Gregory, who may "have a feeling in his favor above any other man who has not the same national and local claims. . . ." The Scots-born Gregory, Kelland's junior by five years and recently graduated as fifth wrangler in 1837, had previously studied at Edinburgh University. But, in a judgment that now seems distinctly unfair to the able Gregory, Hopkins maintained again that: "So far however as Scientific distinction goes we have assuredly no young man here whose merits are established on any thing like the same footing as Kelland's."

---

200 Hopkins (ms.1839).

201 The letter is Hopkins (ms.1838); the printed testimonials are in Forbes (1838). The other testimonials are from De Morgan and Sylvester (himself a former pupil of Kelland) at University College, London; Challis, W.H. Miller, R. Willis at Cambridge; Baden Powell at Oxford; O. Gregory at the Royal Military Academy; G. Fisher at Greenwich Naval Hospital; H. Lloyd and F. Sadleir at Trinity College, Dublin; J. MacCullagh of the University of Dublin; Sir William Rowan Hamilton, Astronomer-Royal for Ireland; and J.D. Forbes himself.

This letter reinforced Forbes' own support for Kelland. Forbes was an aristocratic Tory much influenced by William Whewell, and keen to bring the teaching at the Scottish universities more in line with that at Cambridge. His preference of Kelland over Gregory was at least partly political.[202] In his own testimonial, Forbes alludes to Hopkins' private letter

> from a person whose testimony should have great weight,—I mean Mr Hopkins. . . . Mr Hopkins is in the peculiar position of having had most of the distinguished men of the University of Cambridge, for some years, passing through his hands, as private pupils. He is, therefore, to be supposed to have a more general knowledge of the amount of Mathematical acquirement of rising men, than almost any other individual, and that disembarrassed of the partialities which occasionally, and naturally interfere to give a preference to men of one rather than another college.

But the fact that Hopkins twice underlined the word "young" in relation to Kelland raises the thought that he considered that there was some deserving *older* man. Did he mean himself, or some college fellow such as Samuel Earnshaw? Or perhaps the recently graduated mature student George Green? If himself, was he hoping that Forbes might take the hint and invite him to apply?

Had Hopkins succeeded to Cambridge's Lucasian chair, he would have gained honour rather than remuneration. His tutoring was very well paid whereas the Lucasian chair was not; and it would have been *infra dig.* for a professor to take private pupils. The salary at Edinburgh was also low, but there was extra fee income from students. Whether or not Hopkins coveted the prestige of either post, it seems clear that his contribution to mathematics would have been diminished if he had relinquished his uniquely influential role as a private tutor.

Though neither college fellow nor professor, Hopkins was an integral part of the Cambridge educational establishment. He was a mathematics lecturer at Peterhouse. During the 1830s, he was a syndic (i.e. a committee member) for the building of the Fitzwilliam Museum, and later served as a syndic for its management. He was a stalwart of the Cambridge Philosophical Society, serving as one of its three Secretaries during 1839–51 and as its President in 1851–53: in fact, the first President since the Society's foundation in 1819 who was neither a professor nor head of a College.[203] His weighty and considered evidence to

[202] See Davie (1961), pp.118–123.

[203] Hall (1969), p.97.

the 1850–53 Parliamentary Commission was discussed above; and two more pamphlets by him, from 1841 and 1854, on proposed changes to the syllabus and on wider university reform are outlined below in "Hopkins on Cambridge Education". Another indicator of Hopkins' high standing in the University was his prominent role in securing the unopposed nomination of the Duke of Devonshire as Chancellor in December 1861. Joseph Romilly recorded that a meeting was held at Trinity College with Whewell in the chair: Adam Sedgwick proposed the nomination, and this was seconded by Hopkins.[204]

Beyond Cambridge, Hopkins was a regular supporter of the British Association for the Advancement of Science, and served as its President for the 1853 meeting in Hull. After his retiral from tutoring, he was the British Association's General Secretary during 1861–65.[205]

Through his friend Adam Sedgwick, the Professor of Geology, Hopkins became keenly interested in geology, and he sought to transform it into a subject amenable to mathematical study. Hopkins' ideas became sufficiently in vogue for him to be awarded the Wollaston Medal for 1850 by the Geological Society of London. And he was elected President of that Society for 1851–52. His writings on this subject, and on the related topic of glaciology, are discussed below under the heading "Hopkins and Science".

In 1837, just ten years after his Cambridge graduation, Hopkins was elected a Fellow of both the Royal Society of London and the Royal Astronomical Society. He resigned from the latter body in 1847, but remained a Fellow of the Royal Society until shortly before his death. His Royal Society citation reads:

> Mr William Hopkins MA, of St Peter's College Cambridge, a gentleman profoundly versed in mathematics & many branches of Physical Science & the author of papers of great merit & originality on Physical Geology, the mathematical Theory of sound & other subjects in the Transactions of the Cambridge Philosophical Society & elsewhere, being desirous of becoming a Fellow of the Royal Society, we whose names are underwritten, do certify, of our personal Knowledge, that he is worthy of that honour & likely to prove a useful & valuable member.[206]

204 Bury & Pickles (2000), p.400.

205 Howarth (1931), p.296.

206 His proposers were George Peacock, Adam Sedgwick, J. Cumming, Richard Sheepshanks, Wm Clark, Robert Willis, W.H. Smyth, John Taylor, George Budd, W.D. Conybeare, James D. Forbes, Roderick I. Murchison and John Phillips (Royal Society Sackler Electronic Archive).

Much later, in 1861–62, he served as a vice-president of the Council of the Society.

In May 1851, Joseph Romilly noted that "it is believed that Hopkins will be knighted (because he is one of the 'Jurors' (or prize-awarders) at the Crystal Palace [Exhibition] & is also President of the Geological Society:—I know not how far a knighthood will be compatible with his present position as Esquire Bedell & senior Wrangler Maker: as Esq Bedell he receives about £300 a year, as S.W.M. about £3000 (he taking 40 pupils at 70 Gnas each!)."[207] In fact, Hopkins was never knighted. But Romilly's probably inflated estimate of Hopkins' income shows that he had the consolation of being one of the best-paid men in Cambridge.

Hopkins had cultural interests too: the *Dictionary of National Biography* records that "he took a keen pleasure in poetry and music, had great conversational power, and his sense of natural beauty led to his taking up, not unsuccessfully, landscape-painting late in life as a recreation." It also describes him as "a man of marked dignity of character and most affectionate nature."[208]

As a syndic of the Fitzwilliam Museum, Hopkins was involved with hanging the pictures. Joseph Romilly recorded in his diary for 7 February 1857 that he "went into the Fitzwilliam Museum to see the new hanging: it is very successful & was done almost entirely by Hopkins (the Esquire Bedell)." This was the first rehanging following the furore over Whewell's unilateral action of 1855–56, mentioned in Chapter 4: as Hopkins was appointed a Syndic in November 1856, he would not have been directly involved in the quarrel with Whewell.[209] Romilly also records attending concerts and musical soirées at the homes of friends, including that of the Hopkins family. Once, during tea at the Henslows, "M^{r} & M^{rs} Hopkins sang Italian duetts,—but his singing is always to me very disagreeable:—Miss Fanny & her Aunt thumped out a duett with consid^{ble} execution. . . ."[210]

Hopkins' music making and love of art were noted also by the young William Thomson, who had been invited to a party of Hopkins' students and prospective students:

207 Bury & Pickles (2000), p.87.

208 Anderson (1891).

209 Bury & Pickles (2000), p.271.

210 Bury (1967), pp.16, 146. In contrast, according to Macfarlane (1915, p.134), one of Hopkins' former pupils, the indefatigable textbook-writer Isaac Todhunter, was renowned for being totally tone-deaf: he was said to recognise only two tunes, "God Save the Queen" and one that wasn't, distinguished by the fact that listeners stood up for the former!

> Mr. and Mrs. Hopkins and a young lady sang some glees, and Mr. Hopkins asked all of us whether we performed on any instrument; and when he heard that we did not, he said he was very glad to hear it. After music, conversation, and looking at a great many beautiful prints, we adjourned into another room for supper, which was in very splendid style.[211]

In fact, Thomson *did* play a wind instrument, the cornopean or cornet, and he became a founding member of the Cambridge University Musical Society, which Hopkins also supported.[212]

One of William Hopkins' daughters, Jane Ellice Hopkins (known as Ellice), who never married, deserves mention as a lady of courage and commitment. Joseph Romilly opined that "she is an admirable person: tho' in very delicate health she every week teaches & preaches to the men and boys of Barnwell; I believe her Congregation is entirely masculine." In 1863, she started a charitable appeal for a Barnwell working-men's Hall, to which the men themselves subscribed £40. Her father was to act as its President, and he, together with the Vice-Chancellor and a Dr Humphrey, each donated £20.[213]

Ellice Hopkins wrote many short religious and "improving" works designed for popular distribution, mostly published by a body called "The White Cross Movement". And she campaigned for increased Church of England involvement in improving the conditions of the lower classes. To this end, she wrote several pamphlets, including "A plea for the wider action of the Church of England in the prevention of the degradation of women".[214] A longer work, *Christ the Consoler: A Book of Comfort for the Sick* (J.E. Hopkins 1872), was supplied with a preface by her father's former pupil Harvey Goodwin, now Bishop of Carlisle.

A testimonial fund for William Hopkins was set up in 1860 to mark his retirement from tutoring at the age of sixty-seven; to this William Thomson contributed ten guineas. Probably around November 1861, a celebratory dinner

---

211 Thompson (1910), v.1, p.32.

212 Smith & Wise (1989), p.78.

213 Bury & Pickles (2000), pp.413, 447. Her talents and charitable motives are confirmed by an article in *The Independent* newspaper of 8 June 1863, affirming the "moral and lasting effect" of her sermons upon the lives of the workers and their families (quoted in Bury & Pickles 2000, p.441n).

214 Hopkins, J.E. (1879). Many of her booklets and pamphlets are listed in the Cambridge University Supplementary Card Catalogue, though not in the main catalogue. In 1872, she tried to persuade G.G. Stokes to undertake a series of public lectures on science at Brighton, "a place with 200,000 inhabitants & not even a public library". Hopkins, J.E. (ms.1872).

was held, which Thomson regretted that he could not attend.[215] But Hopkins' retirement was already marred by injury and ill health. Having rented a house at Llewyn Madre in south Wales for the summer of 1860, and perhaps while pursuing his hobby of painting, he had a fall down a steep bank resulting in a severely dislocated knee. After painful surgery, he made only slow progress. Though he assured Stokes in October that he soon hoped to pay a short visit to Cambridge, he was still on crutches and "should be but a piece of useless lumber there now. I can't hope yet to walk alone." Writing again in March 1861, from an address in Brighton, he admitted that progress had been considerably less than expected, though he could now walk at two miles per hour with the aid of a stout stick. In April, he was still receiving daily medical treatment, but soon his doctor would "leave me to our good dame Nature, who, he seems confident, will be able to make a perfect cure."[216]

Despite this physical incapacity, he remained intellectually active. He corresponded with Stokes and Edward Sabine about manuscripts submitted to the Royal Society for publication. He particularly objected to a paper on geology by the Irishman Robert Mallet, for its "profuseness & verbosity". And he was willing to accept appointment to a new mathematical Board of Studies at Cambridge, if Stokes thought it right to suggest his name. A year later, this time in Oxford, he was struggling to provide a report for Stokes on a paper by William Thomson. He had been too unwell during a large part of the summer to deal with this and another "somewhat hard and complicated" paper. In particular, he was finding it difficult to understand "the fundamental principles on which [Thomson's] investigation is founded. I have written to him on the subject, & he has promised to enlighten me further respecting his views."[217]

In May 1864 and now in Bristol, he assured Stokes that: "Since my arrival here my general health is somewhat improved, & my cough shows some little sign of amendment. But 'I must not halloo before I am out of the wood', the rule of the old sportsman, and which ought, as well, to be that of the old invalid."[218] Two years later, on 13 October 1866, he died at the age of 73. Unusually, no Royal Society obituary appeared because Hopkins had resigned his fellowship in 1865, presumably on health grounds; but a full appreciation appeared in the *Quarterly Journal of the Geological Society*.[219]

---

215 Wilson (1990), letters 191, 208.

216 Hopkins (mss.1860; 1861a,b).

217 Hopkins (mss.1861c; 1861a; 1862).

218 Hopkins (ms.1864).

219 Smyth (1867).

Though most sources state that Hopkins died in Cambridge, the *Oxford Dictionary of National Biography* gives the place as Stoke Newington.[220] This is confirmed by his death certificate, which states that he died at Northumberland House Lunatic Asylum, Green Lanes, Stoke Newington, of "chronic mania" and "exhaustion". One may infer that, at the very end of his life, he suffered from some form of dementia: a sad end for one who had been so rational and so dignified.[221]

In his memory, the Cambridge Philosophical Society established the Hopkins Prize for original work in mathematics and physics, awarded every three years from 1867. Fittingly, the first four recipients were G.G. Stokes, J.C. Maxwell, Lord Rayleigh and W. Thomson, three of whom had been his most outstanding pupils.[222] In 1871, G.G. Stokes, with the Master of Peterhouse H.W. Cookson and others, successfully solicited a Government grant for Hopkins' widow, Caroline, in recognition of her husband's merits. Though at first she demurred over applying for a further pension, wishing instead that a smaller one be given to her daughter Ellice, she later acknowledged that she would accept it if offered, to defray the costs of an expensive illness.[223]

Hopkins as Private Tutor

Though Hopkins' charges as a private tutor were high, he gave good value. He was not only an effective "wrangler maker", but an inspiring teacher who fostered the interest of his pupils. He did not teach students in their first year at university, but selected a small class of able students to begin work with him in their second year. College and private tutors were happy to hand over some of their best students to his care. John Hymers of St John's did so in several cases; Frederick Fuller at Peterhouse passed on the brilliant William Thomson; and Matthew O'Brien of Caius urged Francis Galton to transfer to Hopkins, despite Galton's wish to remain.

Galton, who was at Cambridge during 1840–44, soon appreciated his new tutor:

> Hopkins to use a Cantab expression is a regular brick; tells funny stories connected with different problems and is no way Donnish; he rattles us on

220 C. Smith (2004).

221 I am grateful to Alex May of *Oxford DNB* for providing this information.

222 *Cambridge University Calendar, 1909–1910*, p.1293.

223 Hopkins, C. (mss.1871).

at a splendid pace and makes mathematics anything but a dry subject by entering thoroughly into its metaphysics. I never enjoyed anything so much before.

He was also less expensive than Galton had expected, charging "only £72 per annum instead of £100 as currently reported: this will make a jolly difference to my finances." But despite his initial enthusiasm, Galton became a casualty of Hopkins' régime, suffering a breakdown before he could take the final examinations.[224]

Other pupils of Hopkins complained of the demands made upon them. Though he rowed on the Cam, William Thomson worried that, practising for the Easter races of 1844, "It was three weeks clean cut out of my time for working": yet, six months later, he managed to win the silver sculls![225] A year before taking his Tripos examinations, he wrote to his father that "Three years of Cambridge drilling is quite enough for anybody."[226] But we may safely conclude that Thomson was complaining not of exhaustion, but of the intellectually constricting nature of his studies under Hopkins. Yet, later in life, he acknowledged "the greatest possible benefit from his teaching."[227] But Thomson was in no way a typical undergraduate: even during his first year, he contributed original papers to the *Cambridge Mathematical Journal*, and so became well-known to its editors, two Scottish-born Fellows of Trinity, Duncan F. Gregory and Archibald Smith.

Archibald Smith, one of the first of Hopkins' Scottish students, had also complained in 1835 that he was "getting heartily sick of mathematics", and looked forward to being at home "done for ever with the drudgery of mathematics and . . . able to apply myself to more pleasant and profitable studies." Despite becoming senior wrangler, he felt "disgusted" with mathematics.[228]

---

224 Galton's decline is apparent from letters to his father. He started well, and in March 1842 Hopkins complimented him on his mechanics, "which has made me quite jolly. I wish though that I were a better analyst." But already three other members of the class, Buxton, Kay and Edwards, had decided to leave "as their health won't stand it." Against Hopkins' advice, Galton then unwisely attempted to prepare for the Trinity Scholarship examinations on top of Hopkins' demands. The result of such overwork was a major collapse. Some months later, he was still "quite unable to do anything in reading, for by really deep attention to Maths. I can bring on my usual dizziness etc." including palpitations of the heart. As a consequence, in January 1844, he took only the examinations for a poll degree. See Pearson (1914–1930), v.1, pp.153, 163, 166, 167, 173.

225 Thompson (1910), v.1, pp.60, 61; Smith & Wise (1989), p.78.

226 Quoted in Smith & Wise (1989), p.56.

227 Wilson (1990), letter 216.

228 Quoted in Smith & Wise (1989), p.56.

Similarly, C.F. Mackenzie (2nd, 1848) wrote to his sister that: "My mathematical studies are getting on pretty fairly now, though not quite perfectly. The fact is, I sometimes think I have lost that engrossing interest in the subject which I once felt."[229] Harvey Goodwin estimated that he had worked as much as ten hours a day, only surviving because of his strong constitution.[230] And Goodwin's contemporary, the senior wrangler Robert Leslie Ellis, recorded his detestation of the system, "the crushing down of mind and body for a worthless end".[231]

In the October of his second year at Cambridge, William Thomson began study under Hopkins, in a typically small class of about five hand-picked students. In a letter to his father James Thomson, Professor of Mathematics at Glasgow University, William described Hopkins' methods:

> What we have had already approximates very much to the plan w^{h} you pursue with your class. He asked us all questions on various points in the diff^{l} calculus, in the order of his manuscript, w^{h} he has given us to transcribe, and gave us exercises on the different subjects discussed, w^{h} we are to bring with us tomorrow. He says he never can be quite satisfied that a man has got correct ideas on any math^{l} subject till he has questioned him viva voce.[232]

Hopkins could certainly be hard on students who did not measure up to his expectations. C.B. Clarke (3rd equal, 1856) recalled that P.G. Tait's only pupil at Cambridge had begun with Hopkins, but "so unsatisfactory was his progress that Hopkins advised him to seek another tutor. Naturally, the pupil protested and said he would do his utmost not to keep the others back. But Hopkins was obdurate." Tait coached with such success that his pupil came out "one place above Hopkins' best man", and he later boasted that he "could coach a coal scuttle to be Senior Wrangler"![233] Another who did not stay the course with Hopkins was John Venn (6th equal, 1857), who transferred to Isaac Todhunter. It is perhaps significant that both these cases arose towards the end of Hopkins' career, when his success rate was declining.

Hopkins maintained a keen interest in the careers of his former charges, and many of them reciprocated with affection and respect. The

229 Quoted in Goodwin (1864), p.13.

230 Rawnsley (1896), p.45.

231 See Crilly (2006), p.35.

232 William Thomson to James Thomson sr. October 1842 (original in Kelvin Papers, Cambridge University Library), quoted in Smith & Wise (1989), p.76.

233 Knott (1911), p.11, based on a letter from W.A. Porter.

correspondence of G.G. Stokes and W. Thomson contains many considerate references to Hopkins. Henry Fawcett (7th, 1856), blinded in an accident in 1858, was much helped by an encouraging letter from his old teacher: this is remarkable for not dwelling on sympathy, but providing positive suggestions as to how Fawcett should now develop his career. According to Fawcett's biographer Leslie Stephen, Fawcett "always regarded Hopkins as one of the best representatives of all that he most admired in his well-loved University. . . . The spirit of the official Cambridge theory [was] expounded in the best sense by Hopkins—that the true value of the mathematical training was its excellence as a branch of intellectual gymnastics."[234] And even Francis Galton, one of his failures who obtained only a poll degree, mentioned soon after graduating that "I see Hopkins occasionally who often asks me out; he has asked me to dinner tonight and again on Tuesday night."[235]

Some recollections about James Clerk Maxwell as a student of Hopkins have survived. Before Maxwell arrived at Cambridge from Edinburgh, J.D. Forbes wrote to William Whewell commenting both on Maxwell's brilliance and his "exceeding uncouthness" as a mathematician, believing that Cambridge "Drill" was the only chance of taming him.[236] And P.G. Tait (a classmate of Maxwell both at Edinburgh Academy and during their first year at Edinburgh University) recalled that:

> he brought to Cambridge, in the autumn of 1850, a mass of knowledge which was really immense for so young a man, but in a state of disorder appalling to his methodical private tutor. Though his tutor was William Hopkins, the pupil to a great extent took his own way, and it may safely be said that no high wrangler of recent years ever entered the Senate-house more imperfectly trained to produce "paying" work than did Clerk Maxwell.[237]

W.N. Lawson (25th equal, 1854) recalled that Hopkins told him that Maxwell was:

> unquestionably the most extraordinary man he has met with in the whole range of his experience; he says it appears impossible for Maxwell to think

[234] Stephen (1885), p.27. The full text of Hopkins' letter to Fawcett is reproduced in pp.48–51. Stephen states that Fawcett at one time hoped to write an account of Hopkins' work in the University, but this had not come to pass through pressure of other commitments.

[235] Pearson (1914–1930), v.1, p.181.

[236] Warwick (2001), p.137n, quoting from Whewell's Papers.

[237] Campbell & Garnett (1884), pp.87, 88.

> incorrectly on physical subjects; that in his analysis, however, he is far more deficient; he looks upon him as a great genius, with all its eccentricities, and prophesies that one day he will shine as a light in physical science . . .[238]

Maxwell certainly went his own way, pursuing studies well beyond those prescribed by Hopkins. He also made light of Hopkins' set work, once remarking to Lawson, half an hour before they were due to meet Hopkins, "Well, I must go to old Hop's problems"; whereas Lawson had been struggling with them for hours to little effect.[239] But in June 1853, after making himself ill by overwork, Maxwell followed Hopkins' guidance more closely.

Alexander Ellice, the short-lived senior wrangler of 1833, is remembered in a letter written by his friend Archibald Smith. He recalls him as "one of the most lovable men I ever knew—there was a simplicity about his character which was infinitely engaging, unusual[?] in such high talent. . . . Hopkins used to say it seemed quite impossible for him to make a mistake." But Ellice gave up mathematics completely after the Tripos.[240]

Given the highly competitive nature of the Tripos examinations, with likely rewards of fellowships for the winners, Hopkins had to push his pupils hard to give them their best chance of success. Indeed, his own livelihood depended on doing so. In these circumstances, it is to his immense credit that he earned praise for "encouraging in his pupils a disinterested love of their studies, instead of limiting their aspirations to examination honours."[241] According to H.D. Rawnsley, the biographer of Harvey Goodwin:

> Hopkins was strongly opposed to the ordinary idea of cramming for the Senate House. He refused to allow considerations of what would *pay* best in examination to enter the heads of his pupils. He set before his pupils as their first object a clear understanding of the principles of what they were doing, and he urged them to leave all questions of success to take care of themselves.[242]

As much probably cannot be said for Hopkins' successor and former pupil, E.J. Routh, whose efficient coaching methods seem to have lacked Hopkins'

---

238 Campbell & Garnett (1884), p.88n, quoting from Lawson's diary for 15 July 1853.

239 Campbell & Garnett (1884), p.123.

240 Smith (ms.1840).

241 Anderson (1891).

242 Rawnsley (1896), p.41.

wider vision and humanity. Hopkins did not teach first-year students, whereas Routh's intensive plan meant their starting with him in first year. Recorded views of Routh are mixed: among his distinguished former pupils, A.R. Forsyth expressed a harsh opinion, but Karl Pearson was more complimentary.[243]

Hopkins did not restrict his teaching to mathematics alone, but conducted experimental demonstrations for the interest of his pupils. In 1839, he commissioned J.D. Forbes in Edinburgh to arrange for the manufacture of a thermomultiplier to Forbes' design. This device, for detecting small quantities of radiant heat, comprised a thermopile battery and a sensitive galvanometer. When placing his order, Hopkins rather imperiously advised Forbes that:

> your <u>own self interest</u> is perhaps in some measure involved in the matter as there are probably few individuals in the country who have the same opportunity as myself of communicating a knowledge of your experiments to <u>those who can thoroughly understand them</u>. . . . Therefore send me the best apparatus you can, or incur the peril of a certain quantity of scepticism which would be the natural result of unsuccessful experiments . . .

The apparatus was eventually dispatched in October; but it sustained some slight damage in transit, and Forbes was still advising Hopkins on its use in the following March.[244]

Surprisingly, Hopkins published only one mathematical text, a sixty-eight-page *Elements of Trigonometry* issued by the benevolent Society for the Diffusion of Useful Knowledge (Hopkins 1833). In contrast, other leading private tutors—notably John Hymers and later Edward J. Routh and Isaac Todhunter—wrote popular and lucrative textbooks. Todhunter finally gave up tutoring to concentrate on writing, and his textbooks were used in schools and universities around the world.[245] But Hopkins, like other tutors, prepared manuscript booklets for circulation among his students. Student copies of some of these have survived, but apparently no originals in Hopkins' hand. Those that survive include several sets of notes, on mechanics, hydrodynamics, sound and optics, taken by G.G. Stokes from Hopkins' booklets and

243 Forsyth (1935); Pearson (1936). Routh and his pupils are considered in depth by Warwick (2003).

244 Hopkins (ms.1839), Forbes (ms.1840).

245 Barrow-Green (2001).

lectures, and less-complete notes by William Thomson; also later notes by James Clerk Maxwell.[246] These notes, and Hopkins' *Elements of Trigonometry*, give some idea of his teaching style. The standard theory is clearly and succinctly described, and many worked examples are set out, with others left for the student to try.[247]

Charles Bristed observed that "some tutors consider their own manuscripts better than any of the books, and make their pupils copy them", not only to learn their contents but to develop speed and accuracy in writing out standard proofs likely to arise in the examinations:

> A mathematical tutor can drive a much larger team than a classical, . . . the former can be making explanations and setting examples to a squad of eight or ten together. The one to whom I now resorted used to give his thirty pupils regular "fights" as he called them . . . just as in an examination . . . . The men who have taken the very highest degrees do not always make the best tutors. The most celebrated coach for high Mathematical men was a seventh Wrangler [i.e. Hopkins]; our friend of the "fights" an eighth Wrangler [probably William Walton of Trinity College]. . . .

---

[246] Stokes (mss.1838–1840); Thomson (mss.1842–1844). Maxwell (mss.1851–1853). Maxwell's notebooks are entitled "Astronomy", "Differential Equations", "Differential and Integral Calculus", "Hydrostatics, Hydrodynamics & Optics", "Lunar Theory & Rigid Dynamics" and "Statics Dynamics". Some other notes taken by Hopkins' students survive in Peterhouse library: manuscripts by L. Ewbank (13th equal, 1857), "corrected up to 1860 by F.J. Braithwaite" (21st, 1860), are on hydrodynamics, optics, and astronomy; and a booklet copied by E.J. Routh is on the "Dynamics of a Particle" (marked "Hopkins' MSS" on the cover) (Peterhouse mss.).

[247] For instance, in his *Trigonometry*, Hopkins derives the results

$$\sin 18^\circ = \frac{\sqrt{5}-1}{4}, \qquad \sin 15^\circ = \frac{\sqrt{3}-1}{2\sqrt{2}}$$

The second follows easily from the formula for the sine of the difference of 45° and 30°, since sines and cosines of the latter angles are well known; but the first is less straightforward, using the fact that $\cos 3x = \sin 2x$ when $x = 18°$. Hopkins then states further results without proof, including

$$\sin 3^\circ = \frac{(\sqrt{3}+1)(\sqrt{5}-1)}{8\sqrt{2}} - \frac{(\sqrt{3}-1)\sqrt{5+\sqrt{5}}}{8},$$

$$\sin 69^\circ = \cos 21^\circ = \frac{(\sqrt{3}+1)(\sqrt{5}+1)}{8\sqrt{2}} + \frac{(\sqrt{3}-1)\sqrt{5-\sqrt{5}}}{8},$$

which depend on those just obtained, and lists sines of angles at intervals of three degrees. (Hopkins 1833, pp.38, 39).

> The chief requisite of a Poll coach is patience, as his pupils are likely to be very stupid or very lazy, and in either case very ignorant; a man of any ability and knowledge going out in the Poll is able to be his own tutor for the occasion.[248]

But the usual number of students in each of Hopkins' classes appears to have been nearer five than ten.

The most gratifying of Hopkins' annual duties as Esquire Bedell would surely have been that of mace-bearer, flanking the Vice-Chancellor at the graduation ceremonies in the Senate House. There, he must have watched with pride and satisfaction as, one after another, his private pupils received many of the top degrees. One such ceremony is illustrated in the engraving reproduced in Plate 6. This shows Arthur Cayley receiving his degree as senior wrangler in 1842: the figure immediately to the right of the table on which a mace is placed is presumably meant to be Hopkins.[249]

Hopkins on Cambridge Education

As well as Hopkins' lengthy evidence to the 1850–53 Commission already described, he issued two other pamphlets on education that deserve attention. The first is entitled *Remarks on Certain Proposed Regulations Respecting the Studies of the University and the Period of Conferring the Degree of B.A.* (Hopkins 1841). This gives Hopkins' trenchant views on proposed alterations to the degree and examination structure which, though unsigned, came from "the most distinguished members of our body" and bore the address of the Vice-Chancellor.[250] In essence, it was proposed to extend the time spent on theology and diminish that spent on mathematics, in order better to meet the needs of the many students with no particular mathematical aptitude, who intended to train for the priesthood.

Such a move was logical: as remarked of the slightly earlier period around 1800,

[248] Bristed (1852), v.1, pp.204, 205.

[249] Coloured engraving, drawn by R.W. Buss, frontispiece of Huber (1843), v.1. The same event was recorded by Charles Bristed (1852), v.1, pp.130, 131: "Our Trinity Senior Wrangler . . . was a crooked little man, in no respect a beauty, and not in the least a beau. On the day of his triumph, when he was to receive his hard-earned honors in the Senate House, some of his friends combined their energies to dress him, and put him to rights properly, so that his appearance might not be altogether unworthy of his exploits and his College."

[250] John Graham, Vice-Chancellor from June 1840 to May 1841.

> . . . any analysis of Cambridge is bound to be misleading unless it emphasizes another aspect of the University's character: it was a branch of the Church of England. Nearly all Anglican clerics studied at Cambridge or at Oxford. . . . Thus when a man went up to Cambridge he . . . was joining a religious society—a college—in which he could have life-long membership and from which, if he chose to exert himself, he could expect permanent financial and emotional support.[251]

Why, then, should such undue stress be put on mathematical attainments in achieving honours in the B.A. examinations? This, and subsequent debates would lead, slowly and painfully, to a just recognition in 1850 that subjects other than Mathematics and Classics were equally valid for undergraduate study. Hopkins' response is interesting both for its content and for the fact that, though not a Fellow of any college, he felt able to disagree with the University's "most distinguished members". His reputation as a private tutor was such that he expected to be listened to, and he won the day on the most important points.

Hopkins' twenty-four-page pamphlet is a powerful defence of the existing Mathematical Tripos for the more academic students, or "reading men", though he saw no objection to introducing a revised syllabus for the "non-reading men" not aiming for honours. But even this would imply a separation of the Classical and the Mathematical Tripos (a development finally accomplished in 1850). Hopkins' main objection was that any reduction of the syllabus in mathematics would inevitably mean the omission of important *applications* of mathematics to astronomy, optics and hydrodynamics. If these were cut out, then curious students would suffer. Though their number was small, these were precisely the students "selected by the University on account of their mathematical acquirements as fit objects for its rewards" (i.e. who were elected to College fellowships), who went on to form "the tutorial body of the University."

If these applications of mathematics were eliminated, then retaining the theory of partial differential equations and the higher parts of geometry of three dimensions would be anomalous, because these would be put to no practical use. He then remarks on the distinctive nature of Cambridge:

> And here it is important to remark a peculiarity in the character of our institution. Nearly all the rewards which the University has to bestow, are given for the proficiency acquired on the prescribed studies of the place

---

[251] Garland (1980), p.1.

> previous to the B.A. degree. Our system, consequently, supplies in itself scarcely any adequate motive for the subsequent extension of our knowledge beyond the bounds prescribed by the general examination. . . .
>
> . . . If it consisted, on the contrary, of a large body of professors . . . such men would generally be chosen from the mature acquirements of their manhood, and not for the proficiency of their youth. Such is the case in all analogous institutions on the Continent.[252]

(One wonders, at this point, whether Hopkins was thinking of his own "mature acquirements" and his ineligibility, because of marriage, for a College post.) Because of the current nature of appointments, he argues that lowering the standard of the public examinations would injure the University. Both within and outside the University, there was a lack of encouragement for scientific study, with scarcely a dozen public institutions requiring high mathematical attainment. One might think that drawing attention to a lack of demand for mathematics hardly strengthens his case, but his logic becomes clearer. The proposed changes risked damage to "the scientific character of the country" because

> The more distinguished of our students have been conducted, as it were, to an eminence from which they might contemplate the fields of original research before them; and some have been prepared to enter there immediately after completion of their undergraduate course,[253]

a state of affairs that was now endangered.

He goes on to suggest possible improvements to the system. The main one is his recommendation of compulsory attendance at professorial lectures for all honours candidates, though not for others who would find them tedious or unintelligible. But Hopkins' estimate of the "admirable lectures" of Professor Challis was not shared by his pupil, the young G.G. Stokes, who rightly complained of Challis' erroneous views on hydrodynamics.[254] Hopkins ends his pamphlet with an expression of regret that he has had to disagree with distinguished members of the University.

Hopkins' second pamphlet, *Remarks on the Mathematical Teaching of the University of Cambridge* (Hopkins 1854), bears no date of publication, but was issued in 1854, not long after the Parliamentary Commission had published

---

[252] Hopkins (1841), p.12.

[253] Hopkins (1841), p.15.

[254] Craik (2004); Wilson (1987), pp.132, 133.

its report. In its fifty-one pages, Hopkins reacts to the Commission's report and puts forward plans of his own, which he hopes will be considered by the "Studies Syndicate" set up to consider the Commission's recommendations. He strongly supports the collegiate system for imposing moral discipline and superintending the students, and "would reject any plan for the improvement of Public Teaching . . . which should . . . diminish the moral influence of our System." But with regard to the present arrangements for such teaching, "The last forty or fifty years have afforded . . . complete proof of its inadequacy."[255] From shortly after the expansion of the University in 1813–27 up to the present time, effective mathematical teaching had fallen almost completely in the hands of private tutors. Now, even ordinary degree students sought the aid of a private tutor, something unheard of twenty years before. Though men of high quality taught in the colleges, the *system* had failed. No restraints needed to be put on private tutors, but teaching should be reorganised in public University lectures, rather than left to the individual colleges; and these lectures should begin at the start of a student's second year, and not later, as the Commission had proposed.

Hopkins makes detailed proposals for these "Progressive Lectures", to be held in small classes of no more than fifteen students. Each lecturer might take two such classes, each for one-and-a-half hours daily. College tutoring on a one-to-one basis might coexist with these, with regular college examinations, both written and *viva voce*. The public lecturers should be prohibited from taking private pupils, and should hold college appointments only for a limited period: therefore they must be adequately paid. He proposes a basic salary of £300 per annum, supplemented by a £5 fee per term from each student, and extra payment for any summer lectures given. In all, this would amount to £800 or £900 per year. He notes that this compares with the average professorial salary, but that professors had few duties and often held other simultaneous appointments. Hopefully, the professors might also become involved with these Progressive Lectures. The lecturers should be appointed by the Board of Studies and tenure given only after a three- or four-year probationary period. After retirement, the basic salary of £300 p.a. should become a pension for life.

To fund his proposals, he estimates that £2000 to £2500 would be needed each year to pay the basic £300 salary of up to eight lecturers (here he seems to have forgotten to allow for pensions of retired lecturers). A sum of £750 was available towards this from the funds for the ineffective Sadlerian and Barnaby lecturers, regarding whom "I doubt whether a single Undergraduate

---

255 Hopkins (1854), pp.4, 5.

would estimate the advantage which he has derived from them at the value of the smallest coin in the realm." The remaining £1600 to £1700 could come from the colleges. Trinity, St John's and King's were together equivalent in size to the remaining fourteen, making the equivalent of twenty-eight smaller colleges. If £60 per year were given by each small college, and *pro rata* sums from the three larger ones, the required sum would be raised: a good bargain, as £60 was about half the cost of an additional college lecturer. Furthermore, certain extra college fees were paid by every undergraduate for services now largely obsolete, and these also might be transferred to the lecturing fund. In addition, it was possible that for this purpose the Government might agree to remit taxes presently imposed on degrees: if so, the University would gain financially. [256]

As for the Tripos examinations, he again makes a plea for restoration of *viva voce* examinations, not just for the best but for all candidates, but he admits that this process could take up to a month. Apart from this last hobby-horse, Hopkins' proposals made sound sense, despite rather optimistic financial estimates. But they were not adopted. In line with the Report of the 1850–53 Commission, the Sadlerian and Barnaby lectureships were indeed abolished: but Lady Sadleir's bequest went to fund a new chair of pure mathematics, which made little impact on undergraduate teaching.

During the 1870s, courses of intercollegiate lectures were at last introduced, given by the best college lecturers. Five new University lectureships in Mathematics were also created.[257] By the 1880s, the combined efforts of these teachers were organised into a sensible system of university instruction that finally made private tutors less necessary. Had Hopkins' advice of 1854 been acted upon, this improvement would have come thirty years earlier.

Hopkins and Science

From around 1833, Hopkins accompanied his friend Adam Sedgwick on geological field trips.[258] These led him to propose the new field of "physical geology", in which mathematical analysis was used to model geological

[256] Hopkins (1854), p.36ff.

[257] Warwick (2003), p.229.

[258] Sir Charles Lyell (Lyell 1881, v.1, p.405) enthusiastically reported to his friend Leonard Horner that J. Bowstead had spent the Easter vacation of 1834 "geologising in Derbyshire, with a Mr. Hopkins. Is it not delightful to have got such a man fairly bitten?" The editor of Lyell's letters and journals identifies "J. Bowstead" as James Bowstead, later Bishop of Lichfield, who had been second wrangler in 1824; but he may instead be James' younger brother, Joseph Bowstead (2nd, 1833), who had recently graduated under Hopkins' guidance.

phenomena. A lecture on this theme was given by Hopkins to the Cambridge Philosophical Society in 1835. With some glee, Joseph Romilly recorded that: "last Monday Hopkins was delivering a long prosy Lecture on Geology, & before it was over the Master of Downing (who had been snoring for some time) fell flat on his face in the middle of the room to the delight of the company."[259]

Both Sedgwick and Hopkins were early supporters of the British Association for the Advancement of Science. In 1844, they clashed with William Whewell over plans for the Association to meet in Cambridge in the following year. John Herschel had already indicated his willingness to accept the Presidency if the plan were accepted. A meeting was held with George Peacock in the chair, and "Mr Hopkins proposed, in a temperate and well-considered speech, that in case the British Association should decide to meet at Cambridge in 1845, a friendly reception should be given to it". This was opposed by Whewell, who argued that Cambridge had already hosted the meeting in 1833 (when Sedgwick was President), that many other cities had not yet done so, and that considerable expenses would be incurred. Sedgwick's retort was as outspoken as Hopkins had been temperate:

> If the Master of Trinity will not lend us his active cooperation and sympathy, let him at least not oppose the generous wishes of the University—let him go home and shut himself up in his Lodge and receive none of those whom it ought to be an honour and a pleasure to entertain.

But, perhaps aware that he had gone too far, he assured those present that no "difference of opinion upon a question like this could interrupt the life-long friendship that has subsisted between the Master and myself."[260]

Under Hopkins' name, thirty-three publications are listed in the *Royal Society Catalogue of Scientific Papers*. Twenty-two concern aspects of geology, ten are on glacier motion, and one is on sound produced by vibrations in cylindrical tubes. The last-mentioned paper (Hopkins 1835) presents both theory and experiment, intended to model organ pipes and other musical instruments. The open end of the tube was situated close to a glass plate that could be set vibrating with a violin bow. The length of the tube could be adjusted and the local vibrations at points within it detected. The theory proposed modifications of the end conditions that had been used in previous studies. This work seems to have been prompted by a previous experiment in Cambridge by Robert Willis.

---

[259] Bury (1967), p.70.

[260] Clark & Hughes (1890) v.2, p.74.

Hopkins' geological work mainly concerned crustal deformations and fracture, transport of erratic boulders, the nature of the Earth's interior, and climate change. But most of his geological ideas have failed to stand the test of time. For instance, he claimed that the transport of erratic boulders was attributable to the action of large-scale solitary waves in water, which had recently been discovered experimentally by John Scott Russell and which were the subject of theoretical debate. But such boulders are now known to have mostly been deposited by melting glaciers.[261]

Hopkins tried to show that mathematics had a place in geology, and that geological formations were governed by known physical laws and simple mechanical processes. Dislocations could be expected to form along usually parallel lines of maximum shear, which were the result of local elevation of the Earth's crust by increased internal pressure. Furthermore, once these dislocations had taken place, the most likely secondary dislocations would be at right angles. He elaborated these ideas in a privately printed circular expanding on an earlier paper in the *Transactions of the Cambridge Philosophical Society* (Hopkins 1836a,b). But a modern assessment of Hopkins' work is uncomplimentary:

> . . . except in the popularization of quantification and in the broader field of geophysics, Hopkins' effect on contemporary geology was frequently retrogressive rather than progressive. He was often lacking in geological insight . . .[262]

Though Hopkins' geological ideas were sometimes faulty, his work on shear stresses may well have influenced the young G.G. Stokes. Shortly after Stokes graduated, Hopkins advised him that hydrodynamics would be a suitable field of study. Soon after, Stokes derived the full equations of viscous fluid dynamics by adding viscous stresses to the known equations of non-viscous hydrodynamics. When he did so, Stokes was ignorant of related French studies: though based on more tenable physical hypotheses, his equations turned out to be identical to those first derived by Navier, and also to results of Poisson, Saint Venant and Cauchy.[263] The equations are now known as the

261 Russell's experiments and subsequent theory are discussed by Bullough (1998); Darrigol (2003; 2005); Craik (2004; 2005).

262 Beckinsale (1973). A more detailed assessment of Hopkins' geological work and his relations with Sedgwick, William Whewell and others is given in C. Smith (1985; 1989).

263 See Darrigol (2002; 2005).

Navier-Stokes equations. Whether or not Hopkins inspired Stokes, both may have been influenced by work on optics by George Green, who derived similar expressions for the supposed stresses in an elastic model of the "lumeniferous aether".[264]

In three papers published in the *Philosophical Transactions of the Royal Society* during 1839–42, Hopkins made a bold theoretical attempt to discover whether the Earth's interior was solid or liquid, and to estimate the thickness of the Earth's solid crust.[265] The known increase of temperature with depth might cause the interior to remain in its original molten state; but, contrarily, the accompanying increase of gravitational pressure might make it solidify at great depths. He postulated three possibilities: a largely solid Earth containing isolated pockets of molten material that occasionally erupted as volcanoes; an Earth with a solid central core and solid outer crust or shell with molten matter between; and a largely molten Earth with an outer solid crust. By examining the small periodic precession and nutation of the Earth, under the gravitational pull of Sun and Moon, he hoped to distinguish among these three alternatives. In his first paper, following methods outlined in Airy's *Mathematical Tracts*, he calculated the expected precession and nutation of an Earth composed of a solid outer shell and fluid interior, the densities being constant throughout. Disappointingly, he found that the behaviour was virtually the same as for a completely solid Earth, except for cases where the thickness of the solid shell was close to a value around one-fourth of the Earth's radius.

In his second paper, Hopkins supposed that the density was no longer uniform, and he took the internal liquid cavity to be an ellipsoidal shape with eccentricity *different* for that of the Earth's surface. He derived an expression for the expected change of precession, compared with that for a solid ellipsoid of revolution, an expression that depended on the ratio of the two eccentricities. In the third paper, he applied his findings to the actual Earth. Asserting that the observed precession was greater by a factor of about one-eighth than that expected of a solid Earth, he concluded that the internal ellipticity must be about seven-eighths of the outer, and that the thickness of the Earth's solid crust was about 800 miles. Though his hypotheses were too speculative to carry conviction, these papers demonstrated the *possibility* that mathematical studies might reveal information about the Earth that could not be measured directly. The last of these papers was published around the

264 See also Chapters 8 and 12.

265 Hopkins (1839; 1840; 1842).

time that William Thomson became one of his pupils, and such global speculations probably enthused and inspired the young man.[266]

Long after graduating, Thomson felt embarrassed to have to disagree with some of Hopkins' geological work in connection with the rigidity of the Earth. Writing to G.G. Stokes in 1862, he confided that: "I found on looking into Hopkins' papers that, so far as the mathematical problems he attacks are concerned, they are all wrong. . . ." Two of Hopkins' propositions were

> obviously wrong. I have therefore felt great difficulty in referring to his investigation. It was necessary I should do so because he was the first to propose the argument, and I think his conclusion valid. Yet having been one of his pupils, and having experienced the greatest possible benefit from his teaching, I would certainly shrink from the task of finding fault with his investigation.

Thomson's compromise was to insert a footnote in his manuscript; but he feared that "Hopkins, if he notices it, may not be pleased . . . and I should be very sorry to be called on to justify it to him."[267]

Hopkins' interest in stresses and fractures in geology led him to apply his ideas to the motion of glaciers. This work brought him into conflict with James D. Forbes of Edinburgh, who had made extensive studies of glacier motion during field visits to the Alps and Norway. Though most British geologists were sceptical, Forbes had been enthused by the (correct) theory of the Frenchman Louis Agassiz that glaciers had previously been far more extensive, and that they were responsible for many geological features in areas now devoid of ice cover.

In 1841, Forbes joined Agassiz on an expedition in Switzerland. (His travelling companion was John Moore Heath, a mathematical tutor at Trinity College, Cambridge who had been a mere twenty-seventh wrangler in 1830 and perhaps a former pupil of Hopkins.) Sadly, this cordial beginning to the relationship between Forbes and Agassiz soured and degenerated into a bitter priority dispute over their similar theories of glacier motion. In 1842, Hopkins and his former pupil, Harvey Goodwin, also visited the Alps, where they met both Agassiz and Forbes, with Forbes acting as their guide at the Mer de Glace.[268]

---

[266] See also Smith & Wise (1989), Ch.16.

[267] Wilson (1990), letter 216. This is presumably the paper that Hopkins found so hard to understand, mentioned on p.106 above.

[268] The glacier work of Forbes and his contemporaries is comprehensively discussed by Cunningham (1990).

Broadly speaking, whereas Forbes and Agassiz claimed that glaciers slowly *flowed* like a very viscous fluid—and disagreed over which of them had discovered this first—Hopkins for long took the very different view that motion was attributable to successive fracture, slippage, and regelation (re-freezing). The issue was aired publicly when Forbes and Hopkins attended the 1844 meeting of the British Association for the Advancement of Science at York. From there, Forbes wrote triumphantly to his wife that "we have had a lively discussion in the Section on Glaciers, & Hopkins is really floored. He had not a leg to stand upon. . . ."[269]

The rival theories of Forbes and Hopkins were published in the *Philosophical Magazine*, and their conflicting views led to increasingly bitter exchanges in the pages of that journal.[270] Forbes' friend, William Whewell, sided with him against Hopkins, communicating to Forbes a letter that he had received from Hopkins. Forbes responded damningly that

> . . . Mr Hopkins has certainly thrown away his temper with his argument (by way of helping it out) in his reply to you. . . .
>
> Altogether, Mr Hopkins' powers of sticking to his point, or making out any definite point to stick to, appears to me to be shown to very little advantage in the Controversy; there is a confusion of ideas which runs through the whole thing which seems to show that he is not capable of grappling with any subject requiring either force or delicacy.

In similar vein, Forbes' colleague Philip Kelland wrote of Forbes' latest response to Hopkins that "I am glad to see it brings or promises to bring the controversy to a conclusion—The matter seems perfectly plain and Mr Hopkins must have lost temper since he does not see it so."[271]

Though Forbes was in the right on this occasion, it must be observed that he attracted controversy. His letters and publications show a strong combative streak, and many commented on his cold manner, which did little to endear him to either his students or his fellow scientists.[272] A proposal by Whewell

[269] Forbes (ms.1844).

[270] See e.g. Forbes (1845); Hopkins (1845). Many letters relating to this controversy survive among the Forbes Papers in St Andrews University Library, msdep7.

[271] Forbes (ms.1845); Kelland (ms.1845).

[272] Forbes relinquished his Edinburgh chair to succeed David Brewster as Principal of the United College of St Salvator and St Leonard at St Andrews from 1859 to 1868. A St Andrews student of the time remembered him as "a tall aloof man who looked like an icicle and studied congenial topics like glaciers" (quotation supplied by Dr. R.N. Smart).

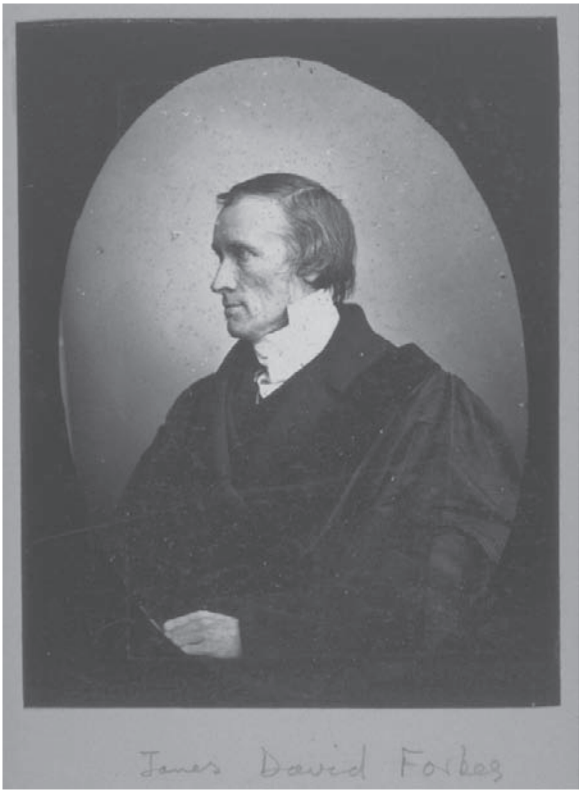


Figure 7. Photograph of J.D. Forbes, c.1850. (ALB10-108: courtesy of University of St Andrews Library Special Collections.)

and others that Forbes be awarded the Royal Society's Copley Medal in 1859 was successfully opposed by his main antagonists, Agassiz, Hopkins and John Tyndall.[273] But Forbes received his fair share of other honours: for his work on radiant heat, he had already received the Keith medal of the Royal Society of Edinburgh and the Rumford medal of the Royal Society of London.

Hopkins' reputation as a geologist seems to have come to no harm as a result of his dispute with Forbes, because he succeeded Charles Lyell as President of the Geological Society in 1851. His presidential address (Hopkins 1852) was a broad geological survey, as was no doubt expected. He mentions several areas in which he had been involved. The transport of large erratic rocks he

[273] Whewell (ms.1859); Murchison (ms.1859).

now accepted as partly attributable to ice "both floating and terrestrial"; and the work of Agassiz and Forbes had clarified the role of glaciers in smoothing and in forming striations on rocks. But Hopkins still urged that the enormous power of water currents and of large waves should not be discounted as agents for moving large rocks and for altering the landscape. (In this he was right, as the destructive power of tsunamis has shown.) He paid tribute to Agassiz "for his warm-hearted hospitalities . . . in the deep recesses of the Bernese Alps, and . . . the perfect unreserve with which he communicated his views to those alike who favoured or opposed them."[274] Though Hopkins had previously resisted the rival glacial theory, he admits that he had finally been convinced by a visit to the Jura. In general, geology was now at the stage in which unsupported speculations were harmful, and more rigorous argumentation was required.

He then surveys recent data from the United States and Canada, and gold finds in Australia. Regarding the latter, "Lord Grey [the Colonial Secretary], it appears, was of the opinion that the discovery of gold in Australia would only be productive of ill effects by deranging all the internal existing relations of the colony." But timely Government action, if taken, could have prevented many of the resulting social evils.[275] Hopkins next discusses changes in the Earth's surface temperature, including a paper of his own concerning the effect of the Gulf Stream. He summarises and contrasts rival theories of "progression" and "non-progression" regarding the evolution of the Earth (see below). He notes the new arrangement of fossils in the Woodwardian Museum at Cambridge, which "owes much to the zeal and private liberality of Prof. Sedgwick", and also the opening of a Museum of Practical Geology. And he concludes by commending the establishment of the new Government School of Mines in London which would liberate mining interests "from the influence of real ignorance and pretended knowledge."[276]

A year later, Hopkins' address as President of the British Association for the 1853 meeting in Hull took a wide view of science suited to the occasion (Hopkins 1853). It catches both the "spirit of the age" and something of Hopkins' personality; and it involves several subjects that reappear in later chapters.

First, he describes recent astronomical discoveries, including that of nine new minor planets in what is now called the "Asteroid Belt" between Mars

[274] Hopkins (1852), p.10. Here, he perhaps intends to point the contrast with the cool, reserved and quarrelsome Forbes.

[275] Hopkins (1852), pp.22–25, 39–40.

[276] Hopkins (1852), pp.44–64.

and Jupiter. He reports the confirmation of Newton's law of gravitation from observation of comets, advances in mapping the stars, and the observation of nebulae through "Lord Rosse's telescope", then the largest in the world. To improve on John Herschel's pioneering observations at the Cape of Good Hope, which used an eighteen-and-a-half-inch reflecting telescope, "It is now proposed to send out to some convenient station in the southern hemisphere a reflecting telescope, with a mirror of 4 feet aperture. Mr. Grubb, of Dublin, has undertaken to construct such an instrument" and Government funding was promised. This telescope went to Melbourne in Australia, and features later in Chapter 10.

In quick succession, Hopkins next reviews terrestrial magnetism; heat (including the steam engine and air engine, and the belated recognition of James Joule's achievements by award of a Royal Society medal); balloon ascents to record meteorological data up to 22,940 feet; and the recently confirmed influence of the Gulf Stream on climate.

Turning to his own preoccupations, he summarises the nature of "physical geology" and points out the need for more chemical studies. Then he mentions experiments by Fairbairn, Joule and himself to determine the effects of pressure on the fusion (or melting) of substances. Though these were restricted to easily fusible substances such as wax, they found that a large pressure produces a substantial increase in the temperature at which melting occurs, a finding with implications for the nature of the Earth's core. Work on earthquakes and fossils had led to two conflicting theories, "progression" and "non-progression". The progressionists believed that the Earth, and the Universe, were in a state of sometimes sudden, irreversible change; whereas the non-progressionists believed in a static, or perhaps periodic, world where physical processes were more gradual and, in principle, reversible. As the science was intertwined with religious beliefs and opinions, this was a contentious area, and Hopkins did not elaborate further.

Reflecting on the role of the Association, Hopkins assures its members that they should not feel disappointed by any absence of striking new discoveries: "Great discoveries do not require associations to proclaim them to the world. They proclaim themselves. . . . We meet . . . to assist and encourage each other in the performance of the laborious daily tasks of detailed scientific investigation." It was not the Association's place to promote "vague theories and speculative novelties" but to encourage "the hard daily toil", and to use its influence to this end, both on its members and on the Government.[277]

277 Hopkins (1852), p.18.

Hopkins commended the recent Great Industrial Exhibition of 1851 for bringing lasting benefit to the mental and moral state of the general population. Better education was now "universally recognised as essential to preserve our future preeminence as a manufacturing nation"; but this must be by sound teaching of the principles of science, not superficial communication of a few curious results. In a passage that must have been dear to his heart as an art lover, Hopkins rebuts the suggestion that study of science is "unfavourable to the cultivation of taste. . . . The sculptor or figure painter must know anatomy; an artist of plants should understand the structure of the leaf"; the landscape painter benefits from knowing the underlying geology; and "will the beauty of the lake be less perfectly imitated by him, if he possess a complete knowledge of the laws of reflexion of light?"[278]

Only in the last paragraph of his address does Hopkins touch on religion. Science, he maintains, allows us to comprehend some of the laws that govern the material Universe, and so better admire its harmony and love its Creator: "There is far more vanity and presumption in ignorance than in sound knowledge; and the spirit of true philosophy . . . is a patient, a modest, and a humble spirit."[279]

Four years later, Hopkins published an essay on "Geology" in a volume of *Cambridge Essays* (Hopkins 1857). This essay, designed for a general readership, tells us more about current religio-scientific debates and Hopkins' own beliefs than it does about geology as such. He begins by recommending the geologist's charming outdoor pursuit: "The mountains and the valleys are the scene of his labours, which he mainly prosecutes under summer influences, and amidst scenes by which nature so often touches and gladdens our hearts. He enjoys the pleasures of the tourist and the artist, combined with his own pursuit." But he warns that "the more complete a science becomes, the less necessary it is for the philosopher who would solve its physical problems to become himself an observer."[280]

He tackles the subject of the formation of the Earth, then much debated by both churchmen and scientists. He dismisses F.R. Chateaubriand's assertion that the world was created in a short time, already complete with fossils. Such a view, then popularly held, was contrary to "the great *argument of design*", whereby physical phenomena must be regarded as due to physical

278 Hopkins (1852), p.19. Many artists of the time expressed similar views, most notably the landscape painter John Constable and the art critic John Ruskin.

279 Hopkins (1852), p.20.

280 Hopkins (1857), pp.172–174.

causes, though divinely ordained.[281] Regarding the division of geologists into two camps, the "progressionists" and the "uniformitarians", Hopkins favoured progression rather than periodic change, as recent advances in natural philosophy had demonstrated the irreversible dissipation of heat and energy. In particular, he maintained that there was no geological evidence for oscillations of temperature over long time scales.[282]

The issue of progression was connected with the evolution or permanence of biological species. Charles Darwin's revolutionary *Origin of Species* (Darwin 1859) was not to appear for a further two years; but the first scientific accounts of the theory of evolution appeared in 1858, in papers by Darwin and A.R. Wallace in the *Linnean Society Journal*. This was shortly after Hopkins' essay was published, but advance notice of these works had probably reached Hopkins, though he does not mention them.[283]

Though making no mention of Darwin or Wallace, Hopkins is critical of a precursor of evolutionary theory, the anonymously published *Vestiges of the Natural History of Creation*.[284] Though based on scant evidence, its author held opinions close to those later advanced by Darwin and Wallace with more convincing scientific support.

Hopkins, though a supporter of "progression" in geology, could not accept the "development theory" from lower to higher life-forms proposed in the *Vestiges of Creation*. This seemed to lead inevitably to materialism, which Hopkins could not admit. Instead, he believed in "reserving for the intellectual, the moral, the spiritual man a distinct creation, as a direct emanation from the Divine Creator." He also rejected the view that a Supreme Intelligence would not need to intervene in the future running of the Universe, once it had been created. This view fallaciously supposed that "the laws self-imposed . . . in the Divine mind . . . were only such as are identical with or resemble those which we, in our weakness and blindness, are able to recognise." Rather, "careful consideration . . . must generally lead to increased confidence . . . that the Creator, for the introduction of new classes of animate

---

281 Chateaubrand's *Genie du Christianisme* had just been reissued in a new edition. The "argument of design" is that of William Paley's *A View of the Evidences of Christianity*, first issued in London in 1794. This had a great success and was published in many later editions.

282 But the matter was less clear-cut than he believed: we now know that there have been recurrent ice ages.

283 Some of Darwin's work was certainly known to Charles Lyell, who urged Darwin to publish it; and Hopkins would regularly have met Lyell at the Geological Society.

284 This was written by Robert Chambers (1802–1871): Chambers (1844).

beings from time to time, has called into action powers altogether different from those which we recognise in the ordinary course of nature." Though there was already a recognition of the need to arrest population growth, then very high in England, Hopkins had no doubt of mankind's continuing existence: "Those who believe man's introduction on the earth to have been a direct act of his Almighty Creator, will not think it necessary to look to his final earthly destiny in the operation of merely secondary causes."[285]

Hopkins did not change these views at a later date. His old pupil, Henry Fawcett, who himself supported the Darwinian theory, confirmed that "Hopkins was of the old school . . . and thinks that Darwinism 'utterly fails' by confusing the difference between hypothesis and proof".[286]

To summarise, Hopkins was a brilliant teacher, a fine though unoriginal mathematician, and a knowledgeable physical scientist who attempted to introduce precise mathematical modelling into geology and glaciology. But his novel attempts to apply mathematics to these areas were largely failures, on account of incorrect hypotheses. His firm, rather orthodox, Christian faith, and his generally conservative philosophical outlook, stood in the way of his accepting new and revolutionary scientific theories like Darwin's: his mathematical mind was unimpressed by the strength of available evidence, which fell far short of proof. But these qualities also defined the personality that made him such a remarkable teacher. He perceived the world as a unity, created by God. To appreciate its beauty and underlying design one must employ the intellect as well as the emotions. He enjoyed art and music, but to him mathematics was the key to physical understanding, and itself the highest of intellectual challenges. He firmly believed that those who attained mastery of mathematics inevitably acquired a high moral character: it was a subject that admitted no dishonesty or incorrect reasoning.

It seems fitting to conclude this chapter with a tribute "by a mathematician of great eminence", sent to Mrs Caroline Hopkins after her husband's death, and reproduced in his Geological Society obituary[287]:

> If I admired Mr. Hopkins at first with the grateful feelings of a pupil, in later years I have been able to estimate better what he did for Cambridge. When he began tuition the reading, I believe, was somewhat unsystematic and in a transition state, as portions of continental works were being infused into the older style of English educational mathematics. When Mr.

---

[285] Hopkins (1857), pp.217, 223, 225, 239.

[286] Stephen (1885), p.99.

[287] Smyth (1867). The writer is probably either G.G. Stokes or A. Cayley.

Hopkins therefore had for so many years the guidance of those who would soon become themselves the guides and examiners of their juniors, we can appreciate what we owe to him in the method in which subjects are treated now. But he had a higher merit yet, I think—in his teaching us to read our subjects in such an honest, thorough way. He tried to raise us above the mercenary spirit of speculating on portions likely to tell in examinations, and led us to read for a more generous and honourable purpose. How effectually he thus brought his pupils to success in the Senate House I need not record; but in a moral point of view, in the formation of character, he was doing better for us than that—in holding before us higher purposes of study than the academic distinctions of the day. Thus his own noble spirit came out in his teaching, and could not fail to influence the pupils at his side.

6.

Hopkins' Top Wranglers, 1829–1854

Portraits of Wranglers: Album and Artist

The portrait album, mentioned in the Preface as residing in Trinity College's Wren Library, was little known for many years. It is a very large, well-bound volume, with each portrait mounted on its own stout page. (Henceforth, it is referred to as the "Wren Library album".) The portraits are the mid-nineteenth century equivalents of modern-day graduation photographs: each subject wears an academic gown and holds a mortar board. All figures are shown three-quarters length, seated. Though the bodies and backgrounds are freely and rapidly sketched, in rather conventional poses, the heads are drawn with great skill and finesse.

There are forty-one numbered portraits, all of William Hopkins' pupils: forty of them are of students who obtained first, second or third place in the Mathematical Tripos examinations. The remaining portrait is of a fourth wrangler (A. Barry), who won the second Smith's Prize and also gained First Class honours in the Classical Tripos. Five more portraits, all of graduates of Trinity College, are added at the back of the album: four duplicate other portraits and one is of a further second wrangler. An accurate list of contents states that the five additions were made in 1931. The portraits are of varying sizes, the largest being 13.75″ × 10.5″ (height × width in inches) and the smallest 9″ × 7″. Most within a rectangular border are signed and dated by Thomas Charles Wageman, whereas the smaller ones are usually octagonal and unsigned. The latter may possibly be by another artist, but are in similar style. Many portraits were made in the subject's year of graduation as B.A., but some are from later: the longest delayed are those of Colenso, fourteen years later, and G. Budd, fifteen years later. The portraits are bound in partial chronological order, haphazardly at first, but by year of graduation from 1844 onwards.

The collection was certainly assembled by Hopkins himself. In his history of Cambridge University, Peter Searby mentions that: "Acting on hints from college tutors, Hopkins chose potential wranglers as his pupils, and gave a supper party for his prospective class in the Michaelmas Term of their first year. At the party he would circulate a portfolio containing likenesses of his successes—a good way to arouse the emulative spirit".[288] The presence of duplicate portraits (three of them signed) confirms that Wageman drew more than one version of his subject. Perhaps the sitters originally kept one copy for themselves and supplied another to Hopkins in thanks for his instruction. But it is also possible that Hopkins himself commissioned the artist.

The collection is described in a 1903 obituary of N.M. Ferrers, Master of Gonville & Caius College:

> For his private tutor the undergraduate Ferrers had the famous William Hopkins, and to this circumstance we are indebted for a contemporary watercolour portrait of the late Master as a Bachelor of the College in pre-photographic days. There is a collection of about forty similar portraits of the pupils of Hopkins, all belonging to the category of Senior, Second or Third Wranglers, now in the possession of the present Master of Trinity. Seven of these portraits, to which an eighth has been added, represent members of our College, and by the courtesy of the Master of Trinity, who allowed us to have copies of them, the copies, including that of N. M. Ferrers, hang in the Combination Room.[289]

The artist Thomas Charles Wageman (c.1787–1863) had his studio in London, as did his artist son Michael Angelo Wageman (fl. 1837–79). Wood's

---

[288] Searby (1997), p.633. His source is an 1841 letter from the young William Thomson to his father: Thomson (ms.1841).

[289] Anon. (1903). I am grateful to Dr A. Crilly for drawing my attention to this obituary of Ferrers. According to Venn (1898, v.3, p.297) the Caius copies were made by a Miss Rosa Carter.

The album bears a donation bookplate from Agnata Frances, widow of Henry Montagu Butler: this is dated 1918, the year of her husband's death. Henry Montagu Butler (1833–1918) was elected Master of Trinity in 1886, after 26 years as headmaster of Harrow School. His second wife Agnata Frances is noteworthy for being placed "above the senior classic" in the Classical Tripos of 1887. Just when the collection came into Butler's possession, and when bound up in its present form, are unknown.

Stuck in the album is a descriptive note by Francis Galton, dated 3 June 1894. Galton had a family connection as Montagu Butler's brother-in-law. In this note, Galton, a pioneer of anthropometrics and eugenics, speculates about a "curious phisiognomical character . . . seen in a little more than one half of these [portraits] . . . a form of forehead adapted to carry long, plain and strongly marked eyebrows . . . It would be interesting to learn how far the independent judgment of others may confirm this conclusion." (The present writer is quite unconvinced.)

Dictionary of Victorian Painters (1971) describes T.C. Wageman as "portrait painter in oil and miniature, and engraver. Exhibited at R.A. [the Royal Academy] 1816–1848. . . . Specialised in portraits of famous actors in their leading roles. Appointed portrait painter to the King of Holland." Many of T.C. Wageman's portraits were commissioned for engravings, some of which he executed himself.[290] Most of these engravings were issued along with magazines and newspapers such as the *Weekly Dispatch*, the *Ladies Monthly Museum*, and the *New European Magazine*. But the wrangler portraits were never intended for engravings. Presumably, the "wrangler market" of individual portraits was sufficiently lucrative to attract Wageman's attention; and his undoubted skill (and probably speed) in achieving good likenesses must have made him a popular choice to commemorate the event of graduation.[291]

These portraits of the forty-two wranglers are reproduced in Plates 7–24, most of them for the first time. Unfortunately, for reasons of economy, several have had to be truncated to shown head-and-shoulders only. (The order in which they appear in the album has not been retained.) Dates are given where known.

General View of the Wranglers

Viewed as a whole, the lives of the forty-two pictured wranglers (identified in bold in Table 1 of Chapter 1, pp. 4, 5) reveal significant common features, shared with nearly all the top wranglers of this period. Their later activities are almost exclusively confined to academia and education, the Anglican church and the law. On graduation, all became fellows of their college at least briefly. Many enrolled at a London Inn of Court to train for the law, but not all who so trained followed a legal career. Many were ordained as priests of the Anglican Church and most of these obtained parishes. Many whose main careers were spent in schools or universities had previously trained and often served as priests, lawyers or both. Almost all taught mathematics (usually as both college fellows and private tutors) at the start of their careers, and some continued to practise mathematics as teachers or researchers after they had

[290] The *British Museum Catalogue of Engraved British Portraits* (O'Donoghue & Hake, 1925) lists sixty entries painted by T.C. Wageman: these range from King George IV and his Queen Caroline, Admiral Sir John Franklin the Arctic navigator, and Sir George Biddell Airy the Astronomer Royal, to the clown Grimaldi and popular actors of the day.

[291] Other artists produced Cambridge portraits around this time. For example, there is a portrait by J.W. Slater of the young Philip Kelland in Queens' College (see Craik 2004).

trained for the Church or law. Later in their careers, some moved between high offices as college heads and senior Church appointments.

A broad categorisation of the forty-two portrait subjects into main areas of activity yields seventeen in academia (professors, fellows etc.), six in school or college education, twelve in the Church, twelve in the law, and one merchant. Here, Barry, Birks, Cayley, Philpott, Porter and Smith are counted twice because they made significant contributions to two areas. Barry was a headmaster, chaplain to Queen Victoria, and bishop of Sydney, Australia; Cayley practised law for fourteen years (while publishing many mathematical papers) before his appointment as the first Sadlerian professor of pure mathematics at Cambridge. Birks was a parish rector and vicar for many years before his appointment as Cambridge's professor of moral philosophy. Philpott became Master of St Catharine's College and was twice Vice-Chancellor of Cambridge University before becoming Bishop of Worcester. Porter practised law before becoming Principal of a college in India and secretary to a maharaja. Smith practised law while active in science and mathematics.

Many others maintained secondary interests and responsibilities. For instance, many churchmen were involved with education, and several academics were prominent in Church affairs. For example, Cowie was Principal of an Engineers' College, a canon and vicar in London parishes, and an Inspector of Schools. Later, he became Dean of Manchester Cathedral where he remained active in promoting education. Kelland frequently preached in church while professor of mathematics in Edinburgh. And Stokes, though not ordained, was "probably the most public religious scientist of the late Victorian period, frequently speaking before Church Congresses and the Victoria Institute, of which he was president."[292] Goodwin, Mackenzie and Colenso, who all became bishops, and the vicars Griffin and W.B. Hopkins were also mathematical tutors and authors.[293] Cadman Jones, a lawyer, was active in Church affairs. Heath, another lawyer, and Ellis, a Cambridge fellow, together edited the works of Francis Bacon and both wrote on a wide variety of other subjects. Hemming, a lawyer, wrote mathematical works, including the unusual *Billiards Mathematically Treated*; while the American-born Pell, the first professor of mathematics and natural philosophy at Sydney University in Australia, was also a barrister and actuary.

The Victorian age allowed more scope for versatility, and for the dilettante, than do the professions of today. Yet it is remarkable that, during this period

[292] Wilson (1987), p.79.

[293] Ferrers lodged as a private pupil in Goodwin's house in Cambridge for a year before joining the University as a student.

of rapid industrial development, entrepreneurship and enterprise, few were active in manufacturing or business pursuits. The Church, Law and Academia were inculcated at Cambridge as the professions fit for a gentleman; and Cambridge connections provided a ready entry.

The only one of the forty-two wranglers to enter "trade" was C.O. Budd: though first training for the law, he was not called to the Bar and instead became a wine merchant, probably in an already-established family business. Only William Thomson, Thomas Main and Archibald Smith were involved with technology. Main, while Professor of Mathematics at the Royal Naval College at Portsmouth, collaborated with a colleague, Thomas Brown, to write a treatise on *The Marine Steam Engine*. Both Thomson and Smith did work on correcting deviations of the magnetic compass in iron-hulled ships. Most spectacularly, Thomson, while Professor of Natural Philosophy at Glasgow, made a fortune by helping to design the first successful trans-Atlantic telegraph cable, and by inventing sensitive electrical and other instruments for which he held many patents. Perhaps envious of his entrepreneurial success, some of his academic associates viewed such commercial enterprise as unfitting behaviour in a scholar.

Though some wranglers came from quite privileged backgrounds, many did not: their origins and pre-Cambridge education were surprisingly diverse. It has been shown that top wranglers tended to come from less affluent homes than did the average Cambridge student.[294] Several were sons of clergymen. The geographical spread was also wide. Of the forty-two of the album, five came from Scotland, four from Ireland and one from the United States. Of the thirty-two from England, eight came from the West Country of Devon, Somerset and Cornwall. Among other known Hopkins students during 1829–54 who are *not* in the album, E.J. Routh was born in Canada and J. Clerk Maxwell was a Scot. Quite a few other Scots were among the top wranglers: up to 1860, these include D.F. Gregory (5th, 1837), H. Blackburn (5th, 1845), G.M. Slesser (1st, 1858), C.A. Smith (2nd, 1858), W. Jack (4th, 1859), J. Stirling (1st, 1860);[295] and Scots continued to feature prominently beyond this time.

Some, mainly the Scots and Irish, had already studied at university before entering Cambridge. Irish Catholics did not of course attend Cambridge: the students who did so were Protestants of Anglo-Irish or Scottish descent. Of the four Irish in the album, Porter and Steele attended Glasgow University in Scotland and O'Brien attended Trinity College Dublin, whereas Stokes

[294] Becher (1984).

[295] Of these, Blackburn and C.A. Smith certainly studied with Hopkins.

attended Bristol College (which, though not a university, had an excellent mathematics master). Of the five Scots, A. Smith and Thomson studied at Glasgow University (where Thomson's father and Smith's grandfather were professors), and Tait at Edinburgh University.[296] Of the others, Todhunter and Routh first studied at University College, London under Augustus De Morgan, and both Cayley and Watson attended King's College, London. All of these were far better prepared for their mathematical studies at Cambridge than were most of their fellow students.

The custom for some of the best graduates of Scottish universities to proceed to Cambridge for further undergraduate study became common from about 1830, and persisted until the mid-twentieth century. This reflected the increase in Cambridge's prestige and the relative decline of the Scottish universities, along with the cachet which a good Cambridge degree came to have in the academic job market. But not everyone approved. For instance, the mathematician and educator Thomas Muir (1844–1934) criticised the practice in his 1884 Presidential address to the Edinburgh Mathematical Society. There, he outlined the typical career of an able Scottish student:

> . . . In time he graduates: this entitles him to compete for a scholarship: he competes, and is successful, leaves for Cambridge, and his University knows him no more. Probably in the newspapers we observe that Mr. Donald Scott of a certain northern university has gained an open scholarship at Johnshouse, and the competition having been between him and a number of men fresh from the English public schools, we are gratified accordingly with his startling success. Gentlemen, I put it to you, if this is a thing for us as Scotsmen to be altogether proud of. When in these cases a young Scotch student competing with English students *of the same age* gains a scholarship, there may be cause for gratulation: but the Scotsman who glories in the part his Universities play in the matter glories in his own shame. . . .[297]

In fact, we must acquit *all* the Scottish and Irish graduates mentioned here of at least part of Muir's charge: most were aged between seventeen and nineteen when they entered Cambridge (though O'Brien may have been twenty), and so were much the same age as the English-born students. This

[296] Thomson, born in Belfast to Irish Protestant parents with Scottish family connections, is usually considered a Scot rather than Irish, because he lived in Glasgow from an early age, but he occasionally referred to himself as being of Irish birth.

[297] Muir (1884); also quoted in Rankin (1983).

was possible because Scottish students then normally entered university at an earlier age, usually thirteen or fourteen; and Thomson, the prodigy, did so at ten. But this changed later.

Several of the forty-two wranglers died young, and so did not reach their full potential: these are Steele (died at age 23), Ellice (28), Goulburn (30), Mackenzie (36), Ellis (41) and O'Brien (41). Others lived to a ripe old age without leaving a scholarly trace: for example, C. Budd, Walker and Heaviside.

In later life, many of Hopkins' and Cambridge's top wranglers interacted in a network of friendships, collaborations, professional contacts and publications. These are reviewed in the succeeding chapters of Part II, which reveal the extent to which Cambridge mathematical graduates dominated the scientific and religious life of their day, both at home and abroad. First, to accompany the portraits of the Wren Library album, brief biographies of each subject are given.

Brief Biographies[298]

Alfred Barry b. London 15 Jan. 1826; d. 1 Apr. 1910: ed. King's Coll. Sch., London; adm. Trinity Coll. 1843. 4th Wrangler, Smith's Prize and 1st class in Classical Tripos, 1848; Fellow 1848. B.D. 1860; D.D. 1866; Hon. D.C.L. (Oxford) 1870; Hon. D.C.L. (Durham) 1888. Adm. Inner Temple 1846. Ord. deacon 1850 and priest 1853. Sub-warden of Trinity Coll. Glenalmond, Perthshire 1849–54; Headmaster, Leeds Grammar School 1854–62; Principal, Cheltenham Coll. 1862–68; Principal, King's Coll., London 1868–83. Canon of Worcester 1871–81, Hon. Chaplain-in-Ordinary 1875–79 and Chaplain 1879–83 to Queen Victoria; Canon of Westminster 1881–83. Bishop of Sydney, Australia, Metropolitan of New South Wales and Primate of Australia 1884–89. Assistant Bishop of

[298] Degrees are those of Cambridge University unless stated otherwise. The B.A. was awarded in the year stated for wrangler. The Cambridge M.A. degree is not shown, there being no further examination: this was usually conferred three years later. Fellowships are held in the college previously attended, unless indicated otherwise. Most details come from J.A. Venn's six-volume *Alumni Cantabrigienses . . . Part II (1752–1900)* and from the *Dictionary of National Biography*, the new *Oxford Dictionary of National Biography*, and the British Library catalogue, but some additions and corrections have been made. The following abbreviations are used: b. = born, d. = died, bro. = brother, ed. = educated at, tr. = transferred to, adm. = admitted to, ord. = ordained, prob. = probably, Coll. = College, Hon. = honorary, Sch. = School, Sen. = Senior, Univ. = University. The list is alphabetical by surname.

Rochester, England 1889–91; Canon of Windsor 1891–1910; Rector of St James's, Piccadilly, London 1895–1900; Assistant Bishop in London 1896. Author of many theological works.

Thomas Rawson Birks b. Staveley, Derbyshire 28 Sept. 1810; d. Cambridge 19 July 1883: ed. Mill Hill Sch., London; adm. Trinity Coll. 1829. 2nd Wrangler 1834; Fellow 1834; Tutor 1834–36. Ord. deacon 1837 and priest 1841; canon of Watton, Herts. and rector of Kelshall 1844–66; vicar of Holy Trinity, Cambridge 1866–77. Knightbridge Professor of Moral Philosophy at Cambridge Univ. 1872–83. Secretary to the Evangelical Alliance for 21 years. Author of theological and scientific works, a popular preacher and controversialist in philosophy.

Joseph Bowstead b. Great Salkeld, Penrith, Cumberland 1811?; d. 15 Oct. 1876: adm. Pembroke Coll., age 16, 1828. 2nd Wrangler 1833; Fellow. Adm. Inner Temple 1834, called to the Bar 1839; Special Pleader, Oxford and Staffs. until 1860; then Inspector of Men's Training Colleges in England and Wales.

Charles Octavius Budd b. North Tawnton, Devon 1821?; d. Torquay 24 Dec. 1890 aged 69: bro. of George; adm. Pembroke Coll. 1840. 3rd Wrangler 1844; Fellow 1848. Adm. Inner Temple 1845 but "no call". Wine merchant.

George Budd b. North Tawnton, Devon 23 Feb. 1808; d. Barnstaple 14 Mar. 1882: bro. of Charles Octavius; adm. St John's Coll. but tr. Caius Coll. 1827. 3rd Wrangler 1831; M.B. and M.L. 1835; M.D. 1840; elected F.R.S. 1836. Fellow 1832–54, Hon. Fellow 1880. Studied medicine in Paris and at the Middlesex Hospital, London. Physician to Hospital Ship, Greenwich 1837–40; Professor of Medicine at King's Coll. London 1840–63; physician to King's Coll. Hospital 1840–63 and medical practice in London 1840–67. Retired to Barnstaple in 1867. Medical author, a leading authority on liver diseases and the cause of scurvy.

Arthur Cayley b. Richmond, Surrey 16 Aug. 1821; d. Cambridge 26 Jan. 1895: ed. King's Coll. London; adm. Trinity Coll. 1838. Sen. Wrangler 1842 and 1st Smith's Prize; Fellow 1842–52; Tutor 1843–46; Hon. Fellow 1872–75, re-elected Fellow 1875. Adm. Lincoln's Inn 1846, called to the Bar 1849; practised as Conveyancer 1849–63. Sadlerian Professor of Mathematics at Cambridge Univ. 1863–95. Elected F.R.S. 1852; awarded Royal Society's Royal medal 1859 and Copley medal 1882. Elected F.R.Ast.S. 1857; President, Roy. Astron. Soc. 1872–74. D.C.L. (Oxford) 1864, Hon. Sc.D. (Cambridge) 1888. Hon. degrees from Edinburgh, Dublin, Göttingen, Heidelberg, Leyden, Bologna. Author of many mathematical works: see Cayley (1889–98).

[John] William Colenso b. St Austell, Cornwall 24 Jan. 1814, d. Pietermaritzburg 20 June 1883: ed. Devonport Sch.; adm. St John's Coll. 1832. 2nd Wrangler 1836 and 2nd Smith's Prize. Fellow 1837–46, Tutor 1842–46. Mathematical master, Harrow School 1838–42. Ord. deacon 1839; vicar of Forncett St Mary, Norfolk 1846–53. Bishop of Natal 1853–83. Excommunicated in 1863 during the "Colenso controversy" but reconfirmed. Author of mathematical textbooks, religious works and works on Africa.

Henry Cotterill b. Ampton 1812; d. Edinburgh 16 Apr 1886: son of rector of Blakeney, Norfolk; adm. St John's Coll. 1829. Sen. Wrangler 1835. Fellow 1835–36. Ord. deacon 1835, priest 1836; D.D. 1857. Chaplain at Madras, India 1836–47. Vice-Principal of Brighton Coll. 1846–51, and headmaster 1851–56. Bishop of Grahamstown, S. Africa, 1856–71. Bishop of Edinburgh 1872–86. Author of several works on religion.

Benjamin Morgan Cowie b. Bermondsey, Surrey 8 June 1816, d. 3 Mar. 1900: ed. Ecole Passy (Paris); adm. St John's Coll. 1833. Sen. Wrangler 1839 and 2nd Smith's Prize; Fellow 1839–43; B.D. 1855, D.D. 1881. Adm. Lincoln's Inn 1837. Ord. deacon 1841, priest 1842; Canon of St Paul's, Knightsbridge, London 1843. Principal of Engineers' Coll. Putney 1844–51; Professor of Geometry, Gresham Coll. 1855. Minor Canon of St Paul's 1856–72; vicar of St Laurence Jewry, London, 1857–72; Inspector of Schools 1857–72. Chaplain-in-Ordinary to Queen Victoria 1871. Dean of Manchester 1872–83. Involved in establishing Manchester High Sch. for Girls, and member of Owen's Coll., Manchester. Dean of Exeter 1883–1900. Compiler of Library catalogues and author of other works.

Alexander Ellice b. Logie House, near Montrose, Scotland, 23 Aug. 1811; d. Ramsgate 21 Apr. 1840: ed. Harrow Sch.; adm. Caius Coll. 1828. Sen. Wrangler 1833 and Smith's Prize; Fellow 1835–40. Adm. Lincoln's Inn 1835, called to the Bar 1839. Died age 28.

Robert Leslie Ellis b. Bath, 25 Aug. 1817; d. Trumpington, nr. Cambridge, 12 May 1859: adm. Trinity Coll. 1834 age 16. Sen. Wrangler 1840 and 1st Smith's Prize; Fellow 1840–49. Adm. Inner Temple 1838. Edited *Cambridge Mathematical Journal*; author of mathematical and other works and co-editor of *Bacon's Works*.

Norman Macleod Ferrers b. Upton St Leonards, Gloucs. 11 Aug. 1829; d. 31 Jan. 1903: ed. Eton Coll.; adm. Caius Coll. 1847. Sen. Wrangler 1851 and 1st Smith's Prize; D.D. 1881. Fellow 1852–80; Dean 1860–65 and Tutor 1865–80; Master of

Caius Coll. 1880–1903; Vice-Chancellor of Cambridge Univ. 1883–85; elected F.R.S. 1877; Hon. LL.D. (Glasgow) 1883. Adm. Lincoln's Inn 1852, called to the Bar 1855. Ord. deacon 1859, priest 1860. Author and editor of mathematical works.

Harvey Goodwin b. King's Lynn 9 Oct. 1818; d. York, 25 Nov. 1891: ed. High Wycombe, Bucks.; adm. Caius Coll. 1835. 2nd Wrangler 1840 and 2nd Smith's Prize; Fellow 1841–45; D.D. 1859; Hon. Fellow 1880. D.C.L. (Oxford) 1885. Ord. deacon 1842, priest 1844; vicar of St Edward's, Cambridge 1848–58; Dean of Ely 1858–69; Bishop of Carlisle 1869–91. Popular preacher and mathematical tutor when in Cambridge. Joint founder of Camden Society 1839. Author of mathematical texts, many religious works, and *Life of Bishop Mackenzie*.

Henry Goulburn b. London, 5 Apr. 1813; d. London, 8 June 1843: adm. Trinity Coll. 1830. 2nd Wrangler 1835 and Senior Classic, 1st Chancellor's medal and 2nd Smith's Prize; Fellow 1835. Called to the Bar, Middle Temple 1840. Died aged 30. Author of legal works.

William Nathaniel Griffin b. London, 28 Jan. or 5 Feb. 1815; d. Ospringe, Kent, 25 Nov. 1892: ed. Christ's Hospital School; adm. St John's Coll. 1833. Sen. Wrangler 1837 and 1st Smith's Prize; Fellow 1837–48. Ord. deacon and priest 1841. Private tutor 1837–47. Committee member and chairman 1843–44 of Cambridge Camden Society. Vicar 1848–92 and Rural Dean 1872–92 of Ospringe, Kent; hon. Canon of Canterbury, 1872–92. Author of several mathematical and physical works.

Douglas Denon Heath b. London, 6 Jan. 1811; d. 25 Sept. 1897: ed. Greenwich; adm. Trinity Coll. 1828. Sen. Wrangler 1832, Smith's Prize and 1st class in Classics Tripos; Fellow 1832. Adm. Inner Temple 1830, called to the Bar 1835; County Clerk of Middlesex 1838–46; Judge of Court, Bloomsbury, London 1838–65. Edited *Bacon's Works* 1859 (with Ellis & Spedding); author of scientific and philological works and papers. A friend of the poets Wordsworth and Tennyson.

James William Lucas Heaviside b. Plymouth, 1 Nov. 1808; d. Norwich, 5 Mar. 1897: ed. Bath and Bristol; adm. Trinity Coll. 1825; transferred to Sidney Sussex Coll. 1827. 2nd Wrangler 1830, 2nd Smith's Prize; Fellow and Tutor of Sidney Sussex; Proctor 1835. Ord. deacon 1833, priest 1834. Professor of Mathematics at the College of the Honourable East India Company 1838–57; its Registrar 1850–57. Canon of Norwich 1860–97. Mathematical tutor to Prince Arthur (later Duke of Connaught). Chairman of Norwich Grammar and Commercial

Schools, Norwich School Board. Senior member of Norwich Cathedral Chapter.

George Wirgman Hemming b. 19 Aug. 1821; d. 6 Jan. 1905: from Tooting, Surrey and Grays, Essex; ed. Clapham Grammar Sch.; adm. St John's Coll. 1840. Sen. Wrangler 1844 and 1st Smith's Prize; Fellow 1844–53. Adm. Lincoln's Inn 1844, called to the Bar 1850; Reporter in Chancery Courts 1859–74; Junior Counsel to the Treasury 1871–75; Queen's Counsel 1875. Standing Counsel for Cambridge University 1875–79; Official Referee 1887–1905; King's Counsel 1903. Author of mathematical works, compiler of *Chancery Reports*, and contributor to the *Saturday Review*.

Lewis Hensley b. London, May 1824; d. 3 Aug. 1905: ed. King's College School, London; adm. Trinity Coll. 1841. Sen. Wrangler 1846 and 1st Smith's Prize; Fellow 1846–56 and Asst. Tutor 1846–52. Ord. deacon 1851, priest 1852; Canon of Upton with Chalvey, Bucks 1852–56; Vicar of Ippolyts with Gt Wymondley, Herts. 1856, and of Hitchin 1856–1905. Author of mathematical textbooks, sermons, contributor to *Christian Antiquities*, and writer of hymns.

William Bonner Hopkins b. Frampton, Lincs., 1822–23; d. 24 Mar. 1890: ed. Barton, Lincs., and Louth & Wakefield Proprietary Sch.; adm. Caius Coll. 1840. 2nd Wrangler 1844 and 2nd Smith's Prize; Fellow of Caius 1844–47; Fellow and Tutor of St Catharine's Coll. 1847–54; B.D. 1854. Ord. deacon 1846, priest 1847; Canon of Holy Trinity, Cambridge 1846–47; Vicar of St Peter's, Wisbech, Cambs. 1854–66, and of Littleport 1866–90. Author of one scientific and several religious works.

Henry Cadman Jones b. 28 June 1818, prob. Repton, Derbyshire; d. 18 Jan. 1902: adm. Trinity Coll. 1836. 2nd Wrangler 1841 and 2nd Smith's Prize; Fellow. Adm. Lincoln's Inn 1841 and called to the Bar 1845. Compiler of several *Reports of Cases at the Court of Chancery*.

Philip Kelland b. Dunster, Somerset, 1808; d. Bridge-of-Allan, Stirlingshire, 7 May 1879: ed. Sherborne School; adm. Queen's Coll. 1830. Sen. Wrangler 1834 and 1st Smith's Prize; Fellow 1835. Ord. deacon 1837, priest 1838. Professor of Mathematics at Edinburgh University 1838–79; Elected F.R.S. 1838, F.R.S.E. 1839; President of Roy. Soc. Edinburgh 1878–79. A founder of the Life Assoc. of Scotland. Author of mathematical books and papers.

Charles Frederick Mackenzie b. Portmore, Peeblesshire, 10 April 1825; d. Malo, Central Africa, 31 Jan. 1862: ed. Edinburgh Academy and Grange School, nr.

Sunderland; adm. St John's Coll. 1844, tr. Caius Coll. 1845. 2nd Wrangler 1848; Fellow of Caius 1848–62. Ord. deacon 1851, priest 1852; Canon of Haslingfield, Cambs. 1851–54. Joined J.W. Colenso as Archdeacon of Natal 1855–59; chaplain to the troops in Natal 1858–59. Head of Universities' Mission to Central Africa 1859; first Missionary Bishop of Central Africa 1861–62. Died of fever aged 36. Author of a mathematical textbook, *Holidays in Linmere*, and *Our Lord's Miracles Explained.*

Thomas John Main b.1812; d. Hampstead, 28 Dec. 1885: from Kent; adm. St John's Coll. 1834. Sen. Wrangler 1838 and 1st Smith's Prize; Fellow 1838–42; elected F.R.Ast.S. 1840. Ord. deacon 1841, priest 1842; Chaplain to the Royal Navy 1842; teacher at gunnery sch. *H.M.S. Excellent*, Portsmouth Harbour. Professor of Mathematics, Royal Naval College, Portsmouth 1846–71. Author of mathematical works, and (with Thomas Brown) *The Marine Steam Engine*.

James George Mould b. prob. Devon 1818; d. Torquay 24 Oct. 1902: adm. Corpus Christi Coll. 1834. 2nd Wrangler 1838 and 2nd Smith's Prize; B.D. 1849; Fellow 1838–55, Tutor 1842–55. Ord. deacon 1840, priest 1848; Rector of Fulmodeston with Croxton, Norfolk, 1868–86.

Matthew O'Brien b. Ennis, Co. Clare, Ireland 1814; d. Jersey, 22 Aug. 1855: ed. Dublin; attended Trinity Coll. Dublin 1830–34; adm. Caius Coll. 1834. 3rd Wrangler 1838; Fellow 1840. Professor of natural philosophy and astronomy, King's Coll. London, 1844–54. Lecturer on astronomy then Professor of Mathematics at the Royal Military Academy, Woolwich, 1849–55. Author of mathematical books and papers.

Morris Birkbeck Pell b. Albion, U.S.A. about 1825; d. Sydney, Australia, 7 May 1879: ed. in U.S.A.; adm. St John's Coll. 1845. Sen. Wrangler 1849 and 1st Smith's Prize; Fellow 1850–52. First Professor of mathematics and natural philosophy at Sydney University, Australia 1852–77. Barrister of Supreme Court of New South Wales 1863; actuary of Australian Mutual Provident Soc. Author of one mathematical text.

Henry Carlyon Phear b. Earl Stoneham, Suffolk, 22 June 1826; d. Croydon, 2 Mar. 1880: ed. at home; adm. Caius Coll. 1845. 2nd Wrangler 1849 and 1st Smith's Prize; Fellow 1850–56. Adm. Inner Temple 1850; called to the Bar 1853; Conveyancer and Equity Draftsman.

Henry Philpott b. Chichester, 17 Nov. 1807; d. Cambridge, 10 Jan. 1892: ed. Chichester Cathedral School; adm. St Catharine's Coll. 1825. Sen. Wrangler 1829 and 2nd Smith's Prize; B.D. 1839, D.D. 1847; Fellow 1829–45; Tutor; Master of St Catharine's Coll. 1845–60; Hon. Fellow 1886; Vice-Chancellor of Cambridge University 1846–47 and 1856–58. President of Cambridge Philos. Soc. 1847. Ord. deacon 1831, priest 1833; Chaplain to the Prince Consort 1854–60; Bishop of Worcester 1861–90; retired to Cambridge.

William Archer Porter b. prob. Drumlee, Ireland, 1825; d. Edinburgh, 16 July 1890: adm. Glasgow University 1841; adm. Trinity Coll. but tr. Peterhouse 1845. 3rd Wrangler 1849; Fellow of Peterhouse 1849, Tutor 1855–56. Adm. Lincoln's Inn 1856; called to the Bar 1859; Equity Draftsman and Conveyancer. Headmaster, Provincial Sch. Kumbakonam, India, 1863–73 and occasional acting Principal of Presidency College, Madras. Principal of Kumbakonam Coll, 1874–78; tutor and secretary to Maharaja of Mysore 1878–82. Bro. of James Porter, Master of Peterhouse.

William Scott b. prob. Devon, 8 Oct. 1825; d. Australia 1888: ed. Hartland School, Tiverton, Devon; adm. Sidney Sussex Coll. 1844. 3rd Wrangler 1848; Fellow 1848–50. Ord. deacon 1849, priest 1850. First Director of Sydney Observatory, Australia 1856–65 and Warden of St Paul's College, Sydney University 1865–82. Author of mathematical text.

Charles Turner Simpson b. prob. Cheshire, 1819; d. Guildford, 10 May 1902: ed. Manchester Free Grammar Sch.; adm. St John's Coll. 1838. 2nd Wrangler 1842 and Smith's Prize; Fellow 1843–55. Adm. Lincoln's Inn 1843; called to the Bar 1846; Equity Draftsman and Conveyancer; Counsel to the Post Office; Bencher.

Archibald Smith b. Glasgow, 10 Aug. 1813; d. Putney, 26 Dec. 1872: attended Glasgow University 1828–32; adm. Trinity Coll. 1832. Sen. Wrangler 1836 and 1st Smith's Prize; Fellow 1836; Hon. LL.D. (Glasgow) 1864. Adm. Lincoln's Inn 1836, called to the Bar 1841; Equity Draftsman. Elected F.R.S. 1856; awarded Royal medal of Royal Soc. 1865. A founder of the *Cambridge Mathematical Journal*, author of mathematical papers and *An Admiralty Manual for Applying the Deviations of the Compass Caused by Iron in a Ship*.

William John Steele b. prob. Co. Donegal, Ireland, 16 Sept. 1831; d. Cambridge, 11 Mar. 1855: attended Glasgow University 1844–47; adm. Peterhouse Coll. 1848. 2nd Wrangler 1852 and 2nd Smith's prize; Fellow 1854 and private tutor. Author with P.G. Tait of *A Treatise on the Dynamics of a Particle*. Died of consumption aged 23.

George Gabriel Stokes b. Skreen, Co. Sligo, Ireland, 13 Aug. 1819; d. Cambridge, 1 Feb. 1903: ed. Dr. Watt's Sch., Dublin, and Bristol College; adm. Pembroke

Coll. 1837. Sen. Wrangler 1841 and 1st Smith's Prize; Fellow 1841–57 and 1869–1902; Master of Pembroke Coll. 1902–03. Hon. LL.D. 1888, Hon. Sc.D. 1888. Lucasian Professor of Mathematics, Cambridge University 1849–1903. Hon. D.C.L. (Oxford) 1855; Hon. LL.D. of Dublin, Edinburgh, Glasgow and Aberdeen. Elected F.R.S. 1852; Secretary 1859–85 and President 1885–90 of the Royal Society; awarded its Copley Medal 1893. Member of Parliament for Cambridge University 1887–91; created Baronet 1889. Author of important papers on fluid dynamics, optics etc.

Peter Guthrie Tait b. Dalkeith, 28 Apr. 1831; d. Leith, 4 July 1901: ed. Edinburgh Academy; attended Edinburgh University 1847–48; adm. Peterhouse Coll. 1848. Sen. Wrangler 1852 and 1st Smith's Prize; Fellow and Tutor 1853–54; Hon. Fellow 1885. Professor of Mathematics, Queen's College, Belfast 1854–60; Professor of Natural Philosophy, Edinburgh University, 1860–1901. Elected F.R.S.E. 1860; Secretary of the Royal Soc. of Edinburgh 1864 and General Secretary 1879–1901; twice awarded its Keith Prize and, in 1886, the Royal medal of Royal Soc.; Hon. Sc.D. (Univ. of Ireland) 1875; Hon. LL.D. (Glasgow) 1901. Author of many books and research papers on mathematics and natural philosophy; also *The Unseen Universe* (with Balfour Stewart). Collaborated with William Thomson and others.

William Thomson b. Belfast, 26 June 1824; d. Netherhall, Largs, 17 Dec. 1907: entered Glasgow Univ. 1834 aged 10; adm. Peterhouse Coll. 1841. 2nd Wrangler 1845 and 1st Smith's Prize; Fellow 1846–52 and 1872–1907. Elected F.R.S.E. 1847, F.R.S. 1851. Awarded Royal Soc.'s Copley medal 1883. Hon. LL.D. (Cambridge) 1866; Hon. LL.D. (Dublin, Edinburgh, Montreal); Hon. D.C.L. (Oxford); Hon. D.L. (Glasgow). Professor of Natural Philosophy, Glasgow University, 1846–99; Chancellor of Glasgow University 1904–07; Pioneer of Atlantic telegraph cables. Knighted 1866; created Baron Kelvin of Largs 1892. President of Royal Soc. 1890–95; and of Royal Soc. Edinburgh 1873–78, 1886–90 and 1895–1907; Order of Merit 1902 and many foreign honours. Influential and wide-ranging scientist; inventor of electromagnetic instruments; author of many important papers on fluid mechanics, heat, electricity, magnetism etc.; author of *A Treatise on Natural Philosophy* and *Elements of Natural Philosophy* (with P.G. Tait), and *Baltimore Lectures.*

Isaac Todhunter b. Rye, Sussex, 23 Nov. 1820; d. Cambridge, 1 Mar. 1884: ed. in Hastings and London. Assistant master at school in Peckham (London), while attending evening classes at University College, London (B.A. 1842); adm. St John's Coll. 1844. Sen. Wrangler 1848 and 1st Smith's Prize; Fellow 1849–64; Hon. Fellow 1874; Sc.D. 1883. Adm. Inner Temple 1857. Elected F.R.S. 1862.

Private tutor in Cambridge. Prolific author of popular textbooks on mathematics and its applications, and of painstaking historical surveys: *A History of the Calculus of Variations*; *A History of the Mathematical Theories of Attraction and the Figure of the Earth*; *A History of the Mathematical Theory of Probability*; *A History of the Theory of Elasticity and the Strength of Materials* (completed by Karl Pearson); also some scientific papers.

Robert Walker b. Gestingthorpe, Essex, 24 April 1824; d. 11 Jan. 1883: adm. Trinity Coll. 1843. 2nd Wrangler 1847 and Smith's Prize. Fellow 1849. Ord. deacon 1851, priest 1852; Canon of Bradfield St Clare, Suffolk 1851–54; Vicar of Helions Bumpstead, Essex 1854–56; Vicar of Wymeswold, Leics. 1856–83.

Henry William Watson b. 25 Feb. 1827; d. Brighton, 11 Jan. 1903: ed. King's College School, London; adm. Trinity Coll. 1846. 2nd Wrangler 1850 and 2nd Smith's Prize; Fellow 1851; Assistant Tutor 1851–53. Adm. Lincoln's Inn 1851. Assistant master at City of London School 1854–56. Ord. deacon 1856; priest 1858. Mathematical Lecturer, King's Coll., London 1857; assistant master at Harrow school, 1857–65. Rector of Berkswell with Barston, Warwickshire, 1865–1902. A founder of the Alpine Club in 1857. Elected F.R.S. 1881; Sc.D. 1884. Author of *A Treatise on the Kinetic Theory of Gases*; *Mathematical Theory of Electricity and Magnetism* (with S.H. Burbury).

William Parkinson Wilson b. Peterborough, baptised 1 Feb. 1826; d. Mornington, Australia, 11 Dec. 1874: ed. Cathedral Grammar School, Peterborough; adm. St John's Coll. 1843. Sen. Wrangler 1847 and 1st Smith's Prize; Fellow 1847–57. Professor of Mathematics at Queen's Coll., Belfast 1849–54; Professor of Mathematics at Melbourne Univ., Australia, 1854–74. Author of *A Treatise on Dynamics.*

George Valentine Yool b. prob. London 1829; d. 6 Nov. 1907: adm. Trinity Coll. 1847. 3rd Wrangler 1851 and 2nd Smith's Prize; 1st class in Nat. Sci. Tripos 1852; Fellow 1853; Assistant Tutor 1853–54. Adm. Lincoln's Inn 1851; called to the Bar 1856; Equity Draftsman and Conveyancer. Author of *An Essay on Law of Waste and Nuisance.*

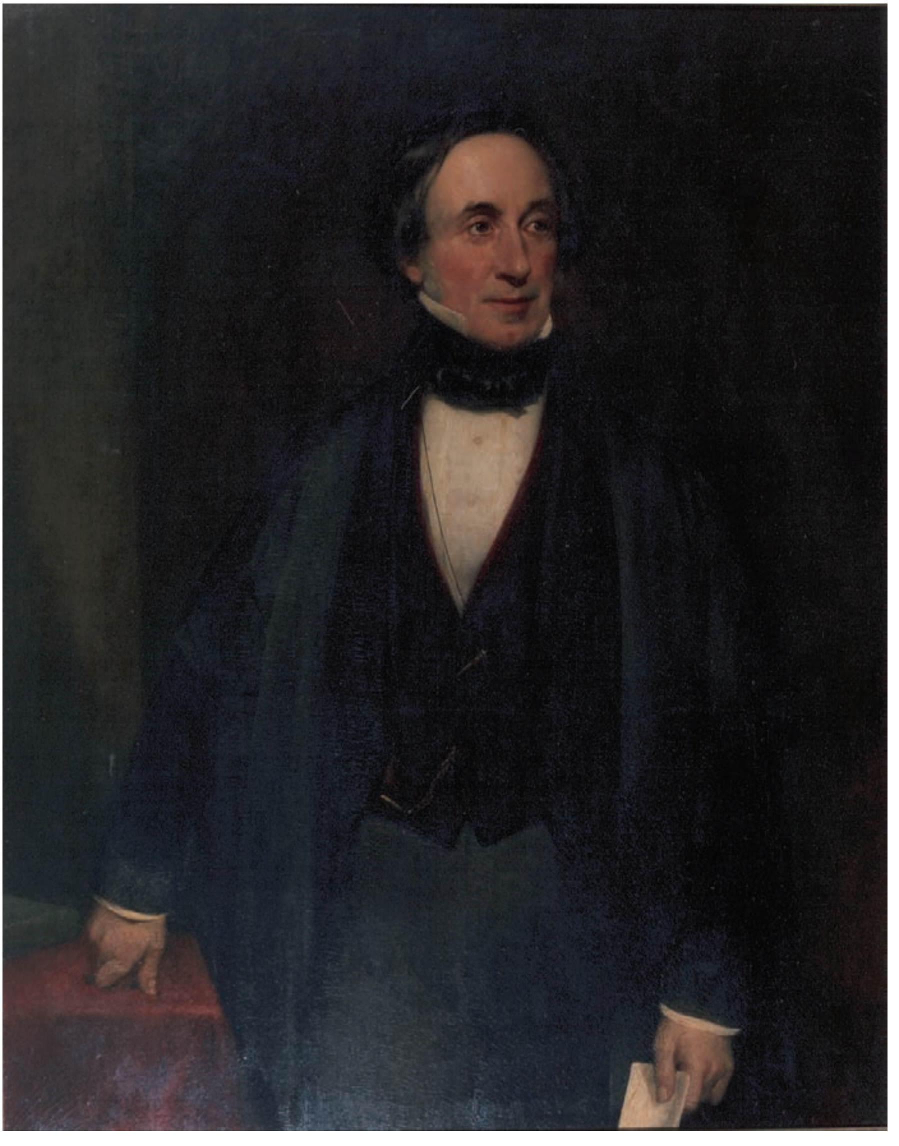


Plate 1. Oil portrait of William Hopkins by H.W. Pickersgill, circa 1860. (Courtesy of the Master and Fellows, Peterhouse, Cambridge.)

Plate 2. Coloured plate of Peterhouse. [From Ackermann (1815).]

Plate 3. Coloured plate of Trinity College Great Court. [From Ackermann (1815).]

Plate 4. Coloured plate of Trinity College Wren Library. [From Ackermann (1815).]

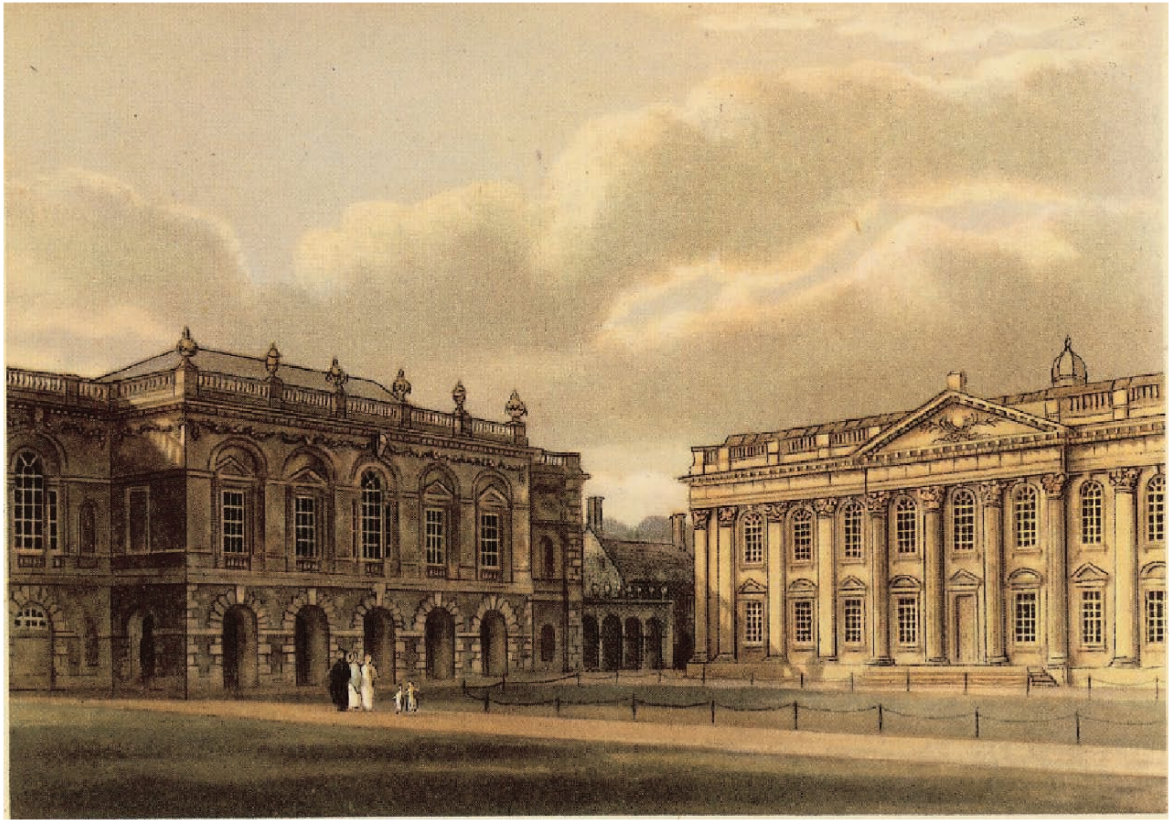


Plate 5. Coloured plate of The Old Schools and Senate House. [From Ackermann (1815).]

Plate 6. Arthur Cayley receiving his degree as senior wrangler in 1842. The figure to the right of the table bearing the mace is presumably Hopkins. [Coloured engraving of drawing by R.W. Buss, from Huber (1843), frontispiece to v.1.]

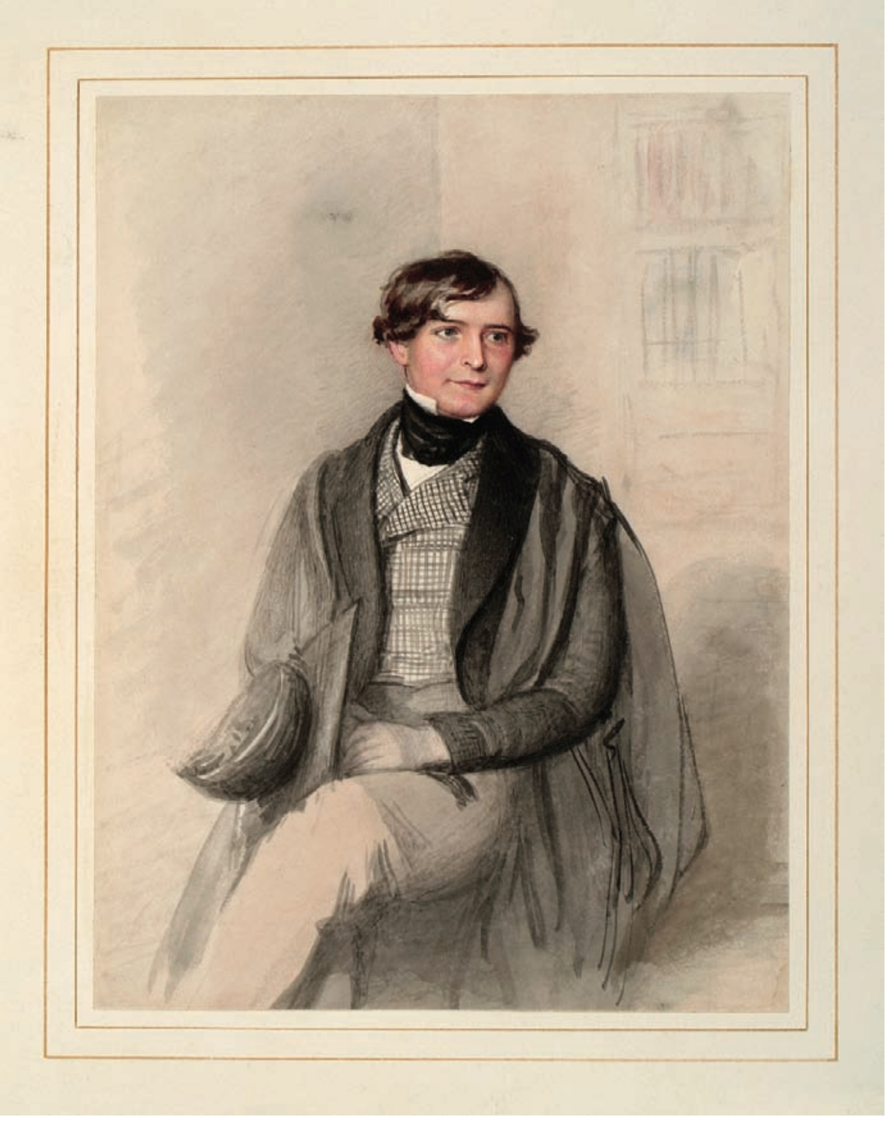


Plate 7. A. Cayley.

Plates 7-24. The forty-two Wren Library pencil and watercolour portraits of Hopkins' top wranglers. (Courtesy of the Master and Fellows, Trinity College, Cambridge.) Dates are shown where known.

Plate 8. J.W. Colenso (1844)

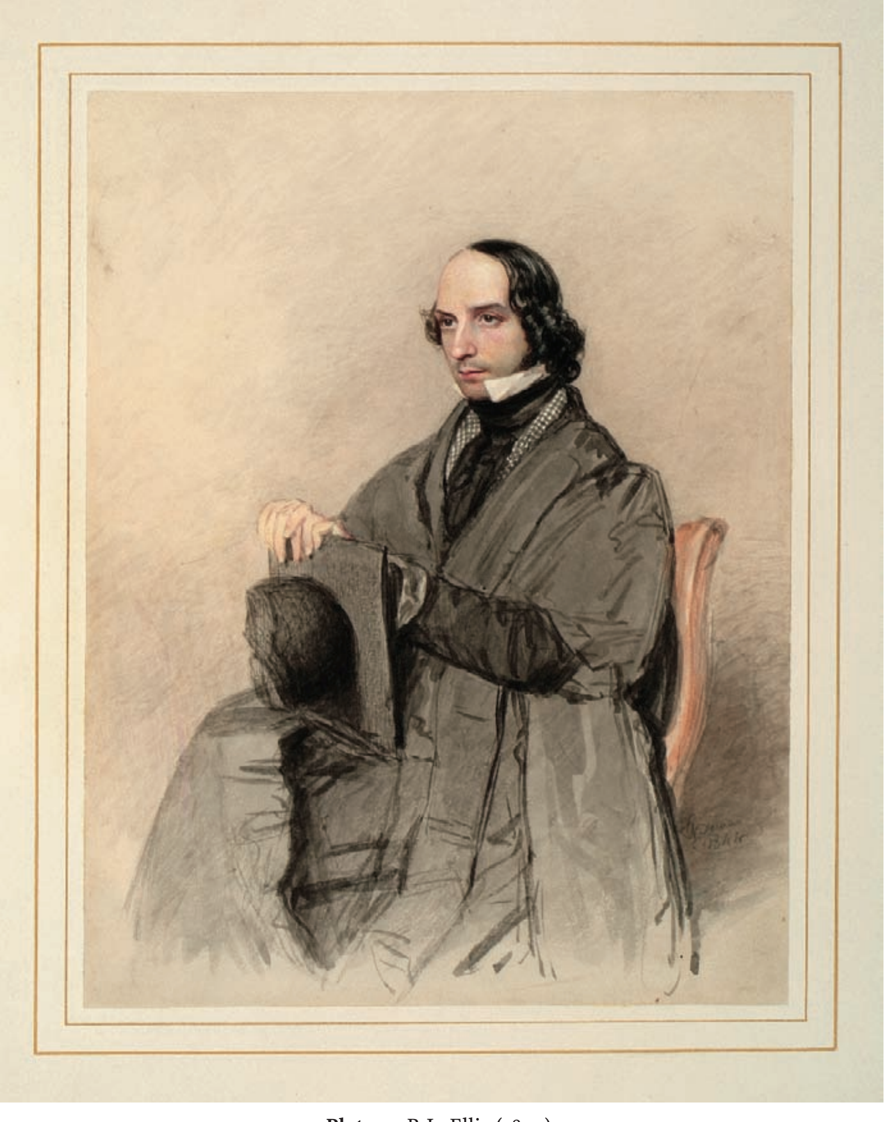


Plate 9. R.L. Ellis (1844)

Plate 10. H. Goodwin

Plate 11. C.F. Mackenzie (1848)

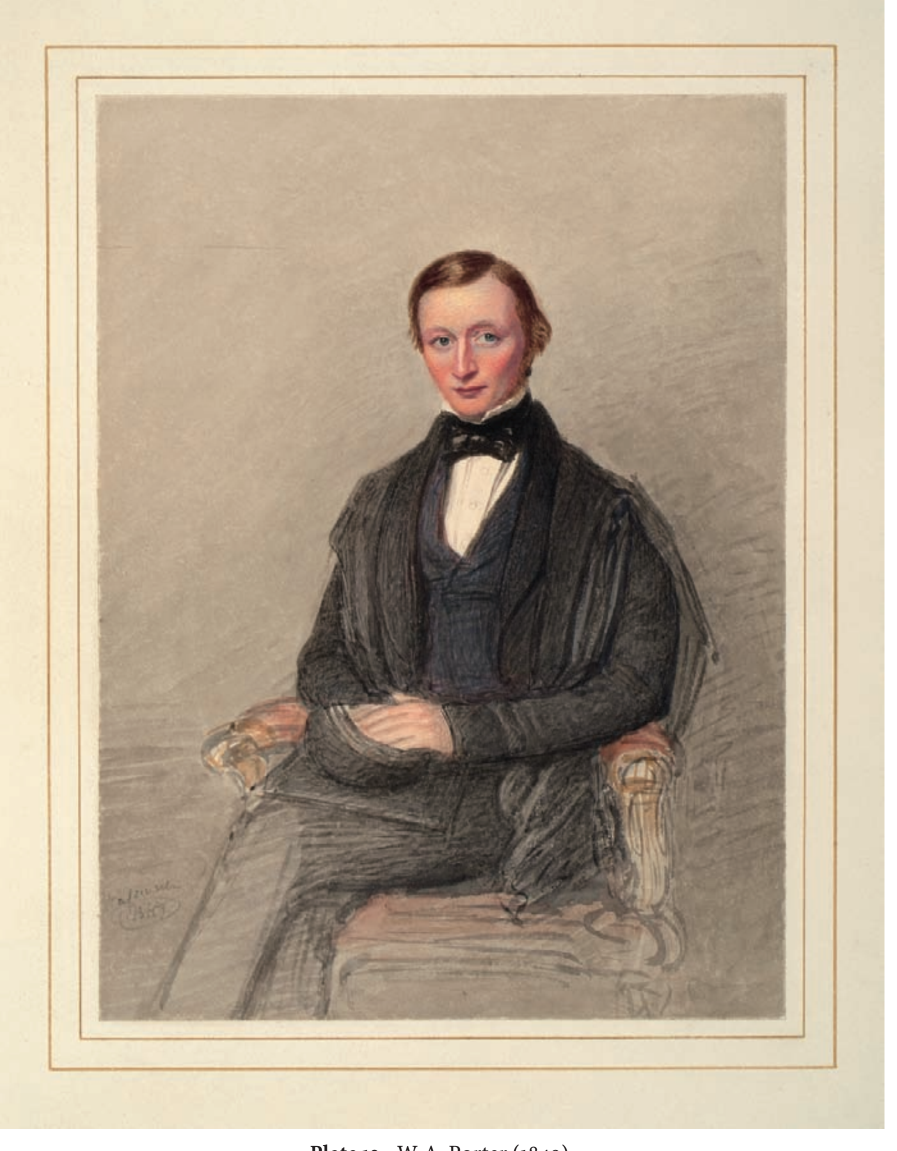


Plate 12. W.A. Porter (1849)

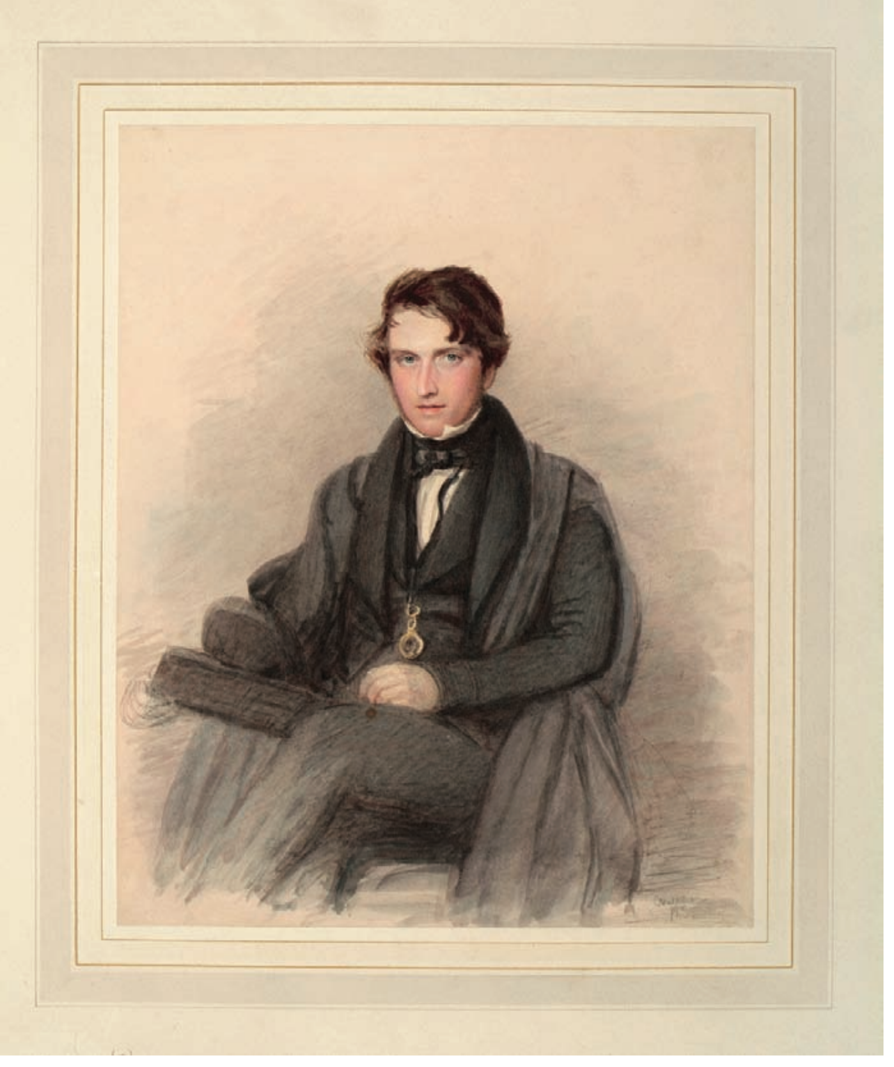


Plate 13. A. Smith (1838)

Plate 14. G.G. Stokes

Plate 15. P.G. Tait

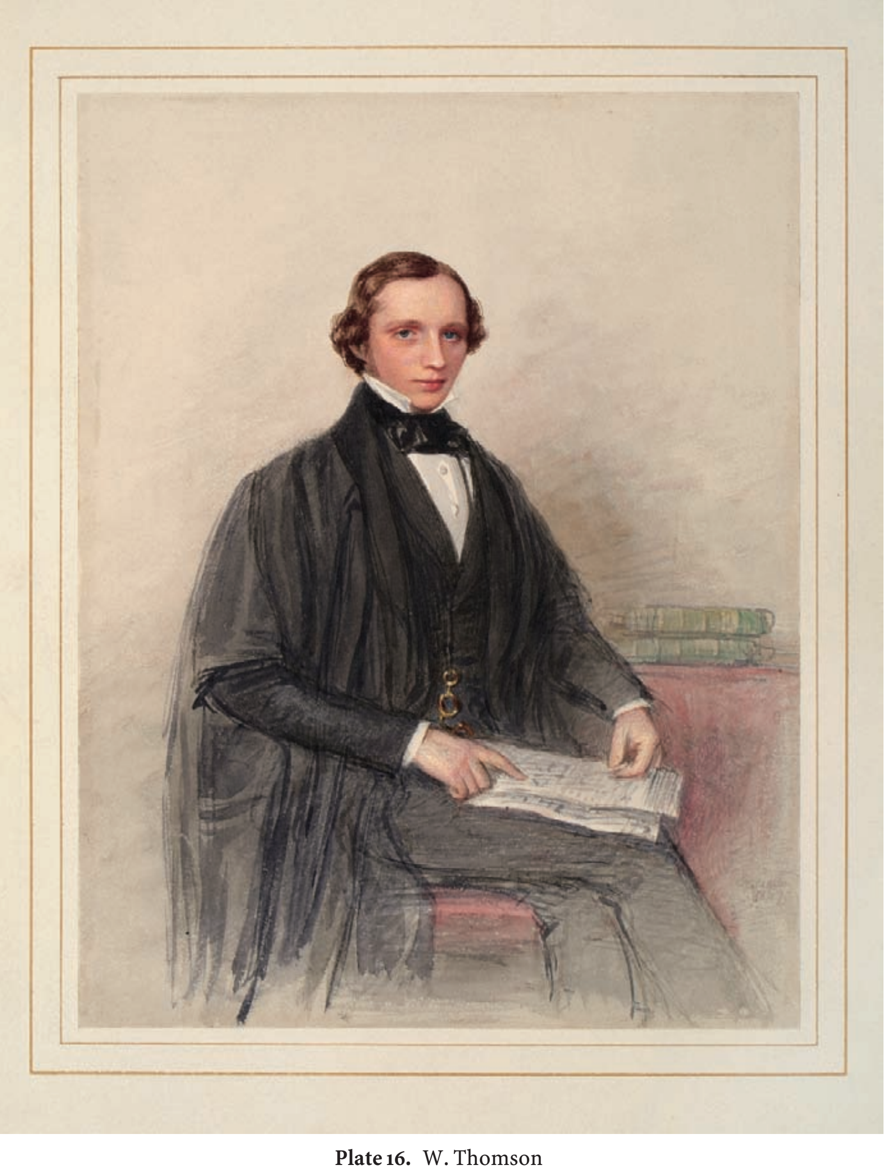


Plate 16. W. Thomson

a

A. Barry (1848)

b

T.R. Birks (1836)

c

J. Bowstead (1836)

d

C.O. Budd (1846)

Plate 17 a–d.

a

G. Budd (1846)

b

H. Cotterill (1835)

c

B.M. Cowie

d

A. Ellice (1835)

Plate 18 a–d.

a

N.M. Ferrers

b

H. Goulburn

c

W.N. Griffin

d

D.D. Heath (1836)

Plate 19 a–d.

a

J.W.L. Heaviside (1835)

b

G.W. Hemming (1844)

c

L. Hensley (1847)

d

W.B. Hopkins (1844)

Plate 20 a–d.

a

H.C. Jones

b

P. Kelland (1835)

c

T.J. Main

d

J.G. Mould

Plate 21 a–d.

a

M. O'Brien

b

M.B. Pell (1849)

c

H.C. Phear (1849)

d

H. Philpott

Plate 22 a–d.

a

W. Scott (1848)

b

C.T. Simpson (1844)

c

W.J. Steele

d

I. Todhunter (1848)

Plate 23 a–d.

a

R. Walker

b

H.W. Watson

c

W.P. Wilson

d

G.V. Yool

Plate 24 a–d.

Part II

Careers of the Wranglers

7. *The "Cambridge Stamp"*

The Benefits of Becoming a High Wrangler

What did a high wrangler gain from his Cambridge education? The pressurised coaching necessary for success certainly gave the top candidates a sound drilling in elementary mathematics, a good knowledge of some more advanced topics, and a familiarity with applications to the physical sciences. The best students were brought to the point at which they could contemplate conducting original research, and several went on to do so. However, some probably felt that the emphasis of their training on amassing examination marks was unworthy of higher intellectual aspirations. Though William Hopkins did what he could to stress the more philosophical aspects of the subject, he knew that speed and proficiency in examination technique were essential to ensure success, and he trained his students accordingly, with regular written tests.

The physical and intellectual demands on these students were great. Habits of intense and protracted study were inculcated, and the best students learned to work both accurately and very fast. Those who succeeded demonstrated stamina and resilience, the ability to work at a high level under severe stress, the capacity to assimilate rapidly a mass of technical information, and to express themselves on paper clearly and succinctly. These assets were to serve them well in later life, often in fields far from mathematics.

The competitive nature of the examinations encouraged another character trait: the will to win. Some wranglers carried through life a strong combative streak and a confidence in their own judgment. Sometimes, this took a fairly benign form, as with William Thomson. Though in some respects a diffident man, Thomson's scientific self-confidence led him to formulate speculative hypotheses, many (though not all) of which turned out to be true. Throughout his long career, he relished the competitive aspect of applying mathematics. This was exemplified during a visit by the German physicist and physiologist, Hermann von Helmholtz. On Thomson's yacht, they tackled together the question of formulating a mathematical theory of short capillary waves, as seen by dangling a fishing line in the moving sea. When Thomson had to go ashore for a few hours, he surprised Helmholtz by instructing him not to work on the problem in his absence, as this would give an unfair advantage in what Thomson clearly regarded as a race.[299]

The combativeness of some others created trouble and controversy. The most remarkable case is that of the theologian J.W. Colenso, to be described later.[300] A naturally stubborn and abrasive personality was probably reinforced by his training: he carried into theology a mathematician's confidence in the rigour of his analysis, and a conviction of the rightness of his unorthodox views.

The narrowness of Cambridge's education, confined mainly to classical languages and to mathematics, was criticised by many. Solomon Atkinson's complaint (described in Chapter 2) that he received no useful preparation for life in the real world had some substance. Yet many top wranglers found time to acquire extra-curricular skills. Some gained extensive knowledge of English literature and of foreign languages; many were proficient players of musical instruments; and some excelled at sports and outdoor pursuits. The fact that so many went on to illustrious careers in fields *other* than mathematics and natural philosophy goes some way to counterbalance the criticisms of the narrowness of formal education offered at Cambridge. A few examples will suffice.

Duncan Gregory (5th, 1837), already well versed in mathematics from his time at Edinburgh University, studied chemistry when at Cambridge, assisting the professor, James Cumming, and as a result probably gaining a lower Tripos place than he merited.[301] According to Charles Bristed, the senior wrangler of his year, Arthur Cayley (1st, 1842)

> had generally the reputation of being a mere mathematician, which did him a great injustice, for he was really a man of most varied information, and that on some subjects the very opposite of scientific—for instance he was well up in all the current novels, an uncommon thing at Cambridge, where novel reading is not one of the popular weaknesses.[302]

One of the most intellectually wide-ranging was Robert Leslie Ellis, the senior wrangler of 1840 and a good classical scholar. Though never in robust

---

299 Smith & Wise (1989), p.738.

300 In Chapter 10 (under heading "The African Bishops").

301 Ellis (1865). James Cumming had been 10th wrangler in 1801 and served as Professor of Chemistry from 1815 to 1861.

302 Bristed (1852), v.1, pp.130, 131.

health, and an invalid long before his early death at the age of forty-one, he was rightly regarded by his peers as a polymath. As well as mathematics, Ellis wrote on subjects as diverse as *Roman Aqueducts*, *Boole's Laws of Thought*, *On the Formation of a Chinese Dictionary*, *Vegetable Spirals*, and *Comparative Metrology* (Ellis 1863). Together with another senior wrangler, D.D. Heath (1st, 1832), and with James Spedding, he also edited a multi-volume scholarly edition of the works of Francis Bacon.[303] Though primarily a lawyer, the versatile Heath numbered the poets Tennyson and Wordsworth among his friends, and he found time to write papers on the tides, on the "doctrine of energy" (praised by Clerk Maxwell), and on Greek prose authors. Isaac Todhunter was a particularly impressive linguist who, as well as the classical languages, reputedly knew French, German, Spanish, Italian, Russian, Hebrew, Arabic, Persian and Sanskrit.[304]

Another Ellis, no relation, was Alexander John Ellis (6th, 1837), whose main claim to fame was as a philologist who collaborated with Isaac Pitman on phonetic writing. He wrote a five-volume work *On Early English Pronunciation* (1869–89) and made English translations of German works on mathematics and acoustics.[305] In addition, Ellis wrote many other disparate books and papers: works on musical pitch, pronunciation for singers, analysis of meteorological observations, and several mathematical texts, most notably *Algebra Identified with Geometry* (1874). More surprisingly, he also wrote a book on *Horse Taming* (1842), based on the methods "practised by the Red Indians of North America."[306]

George Budd (3rd, 1831), who transferred from St John's to the medical college, Caius, in his first year, studied medicine as well as mathematics. Further training in Paris and London led to a distinguished career as Professor of Medicine at King's College, London. And the blind Henry Fawcett (7th, 1856) became Cambridge's Professor of Political Economy and a reforming member of Parliament. Charles Baron Clarke (3rd, 1856) was a keen botanist;

---

303 Ellis was responsible for the philosophical volumes (completed by Spedding after Ellis's death), Heath for the legal ones, and Spedding dealt with the huge remainder. Spedding was a lowly junior optime in mathematics who obtained a second class in the Classical Tripos of 1831.

304 Mullinger (2004).

305 Martin Ohm's *Geist der mathematischen Analyse* (*The Spirit of Mathematical Analysis*), and Hermann Helmholtz's *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* (*Sensations of Tone*, a classic work on musical acoustics).

306 Crilly (2004a), p.137n; McMahon (2004).

and a period spent in India enabled him to build a fine collection of specimens that he presented to Kew Gardens.[307]

Many went on from mathematics to the Anglican priesthood and to high Church positions. Thomas Rawson Birks (2nd, 1834) was just one such, a leading figure of the Evangelical wing of the Anglican Church and Cambridge's Professor of Moral Philosophy. Several other leading churchmen are considered later. Samuel Greatheed (4th, 1835), a founder of the *Cambridge Mathematical Journal*, became a parish priest and a composer of music for the Church.[308] Many others were proficient musicians, among them P.G. Tait, who played in orchestras and supplied a flute obligato at a concert by a "distinguished local soprano" in Belfast.[309] John A.L. Airey (2nd, 1846) and William Thomson were among the founders of the Cambridge University Music Society.

Perhaps the most important advantage of a high Tripos place was its wide recognition as a stamp of excellence, not only in Cambridge but throughout the English-speaking world. The mere fact of a high place was usually enough to ensure election to a college fellowship and a comfortable interlude in which to contemplate the future. The standard path was to study for holy orders, with ordination following after a few years, or to enter one of the London Inns of Court to practise law. The dominant role of Cambridge and Oxford as training grounds for the Anglican Church, and the many parishes in the gift of their colleges, ensured the preferment of their graduates. More than three hundred such posts, in thirty-five counties, were in the gift of the colleges of Cambridge University.[310] After a few years in a parish, those priests who had been high wranglers and fellows became likely candidates for advancement to high office, as chaplains to royalty, canons and deans of cathedrals, and ultimately as bishops, either at home or in the Colonies.

Lawyers, Politicians and Educators[311]

A high wrangler had bright prospects in the law, readily accepted for training at the Inns of Court, and [with the exception of C.O. Budd (3rd, 1844) who, for reasons unknown, received "no call"] quickly becoming a barrister in an

[307] See also Chapter 10, pp.258, 259.

[308] Grove (1906).

[309] Knott (1911), p.12.

[310] Around 350 such parishes are listed in the *Cambridge University Calendar, 1909–10*, pp.810–813.

[311] Except where otherwise indicated, biographical information in this section is mostly taken from Venn & Venn (1940).

established practice. There were four Inns at the time: Lincoln's Inn, Gray's Inn, the Inner Temple and Middle Temple, each with a collegiate atmosphere resembling that at Oxford and Cambridge. Many of the lawyers served as equity draftsmen and conveyancers, and several were involved in legal publications such as the *Chancery Reports*. Some became judges or legal counsels to major enterprises: for instance, Anthony Cleasby (3rd, 1827) was a barrister and served as Baron of the Exchequer during 1868–78; Douglas Denon Heath (1st, 1832) was a county court judge; Colin Blackburn (8th, 1835) became a noted High Court judge and then a Lord of Appeal; George W. Hemming (1st, 1844) was a chancery court reporter for thirty-five years and served as counsel to Cambridge University; and Charles T. Simpson (2nd, 1842) was counsel to the Post Office. Arthur Cayley (1st, 1842) practised as a conveyancer for fourteen years, writing mathematical papers in his spare time, before his election as the first Sadlerian Professor of Pure Mathematics at Cambridge.

Relatively few high wranglers pursued careers in politics, and those who did so usually first undertook a legal training. Though Henry Fawcett's blindness, caused by an accident, brought his legal studies to an abrupt halt, he went on to a notable Parliamentary career as a radical and reforming Liberal. Believed to be the first blind member of Parliament, he represented the constituencies of Brighton and then Hackney, and became a well-known public figure. Concerns over his disability denied him a seat in the Cabinet; but he was a formidable campaigner for a range of Liberal causes, and for a time served successfully as Postmaster General, when he introduced the first parcel post. Among the causes that he championed were votes for women, the abolition of religious tests in universities, the preservation of common land from private ownership, and fairer administration of British India.

His popular *Manual of Political Economy* (1863) was published just in time to secure his appointment as Cambridge's Professor of Political Economy, ahead of his friend Leonard Courtney (2nd, 1855). He held the chair from 1863 until his death in 1884; but he had few official duties and few able students, there being no examination in the subject. A populariser rather than an original theoretical economist, Fawcett held opinions much influenced by those of John Stuart Mill. His later articles were devoted to socio-economic matters such as pauperism and its causes, free trade, and state Socialism.[312]

One of the first successful lawyer–politicians among our wranglers was Edinburgh-born Samuel Laing (2nd, 1832), who in 1842 became secretary to the Board of Trade responsible for railways. In 1848, he then became chairman and managing director of the London, Brighton, and South Coast Railway, and served terms as Liberal member of Parliament for Wick in northern

[312] Stephen (1885); Goldman (2004).

Scotland. Returning to government administration, he was briefly financial secretary to the Treasury and, during 1860–65, financial minister to the crown in India. On return from India, he was re-elected MP for Wick during 1865–68, and then for Orkney & Shetland in 1873–85.[313] Laing returned in 1867 to head the London, Brighton, and South Coast Railway Company, helping to rescue it from imminent bankruptcy, and remaining its chairman until his retirement in 1894. On leaving Parliament at the age of seventy, he turned to writing: his popular *Modern Science and Modern Thought* (1885) espoused the evolutionary ideas of Darwin and Huxley, exposing the contradictions between recent scientific data and traditional religious views. His later works on similar themes, though unoriginal, were clear and interesting expositions of important subjects, that showed his wide command of scientific matters.[314]

While at Cambridge, James Wilberforce Stephen (4th, 1844) had been tutored by William Hopkins and was a rowing companion of William Thomson. After study at Lincoln's Inn, he was called to the Bar in 1849, but left for Australia in 1855. In Melbourne, he rapidly built up a successful legal practice. In 1871 he was elected to the Victoria Legislative Assembly and served as its Attorney-General during 1872–74. At this time, he successfully promoted a Bill for "free, compulsory and secular education in Victoria", and he served as the First Minister for Public Instruction. In 1874 he resigned from political life on being appointed a Judge of the Supreme Court of Victoria.[315]

Another who entered politics was John Eldon Gorst (3rd, 1857). After a few years as a fellow of St John's, he went to New Zealand, at first working for Bishop Selwyn's mission to assist the Maori people, then entering government service. He rose to become civil commissioner for Waikato, but a quarrel with the Maoris over his imposition of English ideals led to his return to England in 1864. There, he was soon called to the Bar of the Inner Temple, and elected Conservative MP for the borough of Cambridge. In 1870, he was appointed by Disraeli as the Conservative Party's central agent, when he did much to modernise the Party administration and to support Disraeli's position as leader. Subsequently, he built up an extensive legal practice as Queen's Counsel, received a knighthood in 1886, and held successive government appointments

313 Appropriately so, for his father had been a prominent Orcadian, a popular writer and, for a time, provost of Kirkwall.

314 Seccombe (2004).

315 Thompson (1910), pp.40, 59, 76; Chisholm (c.1958). Some of Chisholm's dates, given above, differ from Venn & Venn (1940).

as solicitor-general, parliamentary under-secretary at the India Office, and financial secretary to the Treasury. Disappointed not to be put in charge of the Education Act of 1902, he resigned to campaign for social reform and improvement of the health of schoolchildren. As MP for Cambridge University during 1891–1906, he frequently attacked the government, and sat as an independent for his last three years.[316]

Penzance-born Leonard Henry Courtney (2nd, 1855) became a Lincoln's Inn barrister but rarely practised law, instead preferring journalism. During 1856–81, he was a leader-writer to *The Times* newspaper, penning around three thousand articles with a Liberal political slant. During 1872–75, he was also professor of political economy at University College, London. As Liberal member of Parliament for Liskeard (1876–85) and Bodmin (1886–1900), both in Cornwall, he was often at odds with the Government over his support for proportional representation and women's suffrage, and his opposition to imperialist expansion in Africa. He "often irritated the Commons by his portentous and long-winded speeches, which reflected the worst features of his experience as a leader writer and professor." But he was an able administrator, who held posts under W.E. Gladstone during 1880–84 as under-secretary for the Home Office and for the Colonies, and financial secretary to the Treasury. He then served as deputy Speaker from 1886 until 1892. He was appointed to the peerage in 1906, becoming Baron Courtney of Penwith.[317]

John Rigby (2nd, 1856) became a Queen's Counsel in 1881, and was a member of Parliament during 1885–86 and 1892–94: during the latter period, he held the legal posts of Solicitor General, Attorney General and Lord Justice of Appeal. He received a knighthood in 1892.

Charles Abercrombie Smith (2nd, 1858) was one of the Peterhouse Scots, born in Glasgow and an M.A. of Glasgow University before attending Cambridge. After a brief period as a fellow of Peterhouse, he went to Cape Province in southern Africa, where he held a series of important administrative posts.[318]

Rather later, John Fletcher Moulton (1st, 1868) had a distinguished legal career. After some years as a mathematics lecturer and assistant Tutor of

---

[316] Feuchtwanger (2004).

[317] Matthew (2004).

[318] Member of the Cape Legislative Assembly (1866–75), Commissioner of Crown Lands and Public Works (1872–75), Controller and Auditor General (1875–1903), Vice-Chancellor of the Cape University (1877–79, 1905–09), and Chairman of the Civil Service Commission (1887–1910). He married late, in 1897, at the age of sixty-three, and died aged eighty-five at Wynberg, near Cape Town.

Christ's College, he was called to the Bar in 1874 and was intermittently a member of Parliament for various constituencies. He was knighted in 1906 and served as a Judge to the Court of Appeal for the next six years. He was then made a life peer and, during 1912–21, was a Lord of Appeal in Ordinary and a member of the Judicial Committee to the Privy Council.

It is surely no coincidence that several of the above lawyers and politicians held finance-related posts, for which a high level of numeracy was required. Others who did so were the mathematician J.J. Sylvester (2nd, 1837), who during 1844–55 was actuary and later *de facto* chief officer of the Equity and Law Life Assurance Society; and the barrister and actuary Thomas Bond Sprague (1st, 1853), a fellow of St John's until 1860, who became manager of the Scottish Equitable Life Assurance Company and who wrote several works on life insurance.

As the reputation of the mathematical Tripos grew, so too did the demand for Cambridge-trained scholars to fill teaching and academic posts throughout the country and in the Colonies. Once Cambridge graduates were installed in schools, universities and colleges elsewhere, it was natural that they should encourage their own best students to follow the same path. This in turn benefited Cambridge, providing a regular source of talent, sometimes from parts of the United Kingdom that had previously been under-represented. Furthermore, those students who *arrived* with a prior university education (mainly from Scotland or from University or King's Colleges in London) had an intellectual maturity greater than that of most undergraduates. With this advantage, it is not surprising that many did well. Some Cambridge colleges were more influenced than others, as new students tended to follow in the footsteps of their teachers.

Chapter 9 surveys the colleges and universities in England, Scotland, Ireland and overseas. In addition, Cambridge wranglers held key appointments at leading schools, fostering mathematics and recommending Cambridge to their best pupils. For instance, J.H. Evans (3rd, 1828), C. Pritchard (4th, 1830), A. Barry (4th equal, 1848) and J.M. Wilson (1st, 1859) were headmasters at Sedbergh, Clapham Grammar School, Leeds Grammar School and Clifton College respectively; J.A.L. Airey (2nd, 1846) taught at Durham School and the Merchant Taylor's School in London; and R.B. Mayor (3rd, 1842) and C. Elsee (3rd, 1855) were long-time mathematics masters at Rugby school. Other wranglers, such as H. Moseley (7th, 1826), B.M. Cowie (1st, 1839) and W. Baily (2nd, 1860), served as Government inspectors of schools.

As well as the direct educational benefit of studying at Cambridge, one must not forget the parts played in academic and other appointments by personal acquaintance, close intellectual contacts, political affiliation and, occasionally, downright nepotism. In these regards, the dominance of

Cambridge wranglers became virtually unassailable in mathematics and natural philosophy. Sometimes, the academic network was reinforced by marriage to relatives of friends, colleagues or teachers—a natural enough consequence of the difficulty of meeting female company in male-dominated Cambridge. To mention just a few, Harvey Goodwin married a niece of Joshua King the Lucasian professor of Mathematics; E.J. Routh married a daughter of the Astronomer Royal G.B. Airy; P.G. Tait married a sister of his friends J. and W.A. Porter; the astronomer Robert Main married a sister of his Queens' College contemporary, Philip Kelland; the Irishman G.G. Stokes married the daughter of T.R. Robinson, astronomer at Armagh Observatory; John Couch Adams married a close friend of Stokes' wife; and William Whewell's second wife was the widowed sister of R.L. Ellis. One notable exception was Archibald Smith's objection to his sister Sabina's accepting a proposal of marriage from William Thomson. She turned him down, Thomson soon afterwards married his cousin Margaret Crum, and Sabina Smith rued her decision.[319]

The Anglican Church at Home and Abroad

The near-monopoly of Oxford and Cambridge Universities (or rather their constituent colleges) on appointments to the Anglican Church has already been mentioned. Because of the idiosyncratic nature of the Cambridge system, many leading Anglican churchmen at home and abroad had considerable mathematical accomplishments, at this time as at no other. In addition to the six Wren Library album subjects who became bishops—Barry, Colenso, Cotterill, Goodwin, Mackenzie and Philpott—two others among the top three wranglers were C. Perry (1st, 1828), Bishop of Melbourne, Australia, and R. Rawle (3rd, 1835), Bishop of Trinidad.

No fewer than twenty-seven Cambridge graduates from the twenty-three years 1828–50 went on to become bishops. Of these, eleven were wranglers, eleven were Senior Optimes and four were Junior Optimes.[320] Several but by no means all the bishops who got undistinguished mathematical degrees did well in the Classical Tripos. Between them, they held fourteen bishoprics in

[319] Smith & Wise (1989) pp.141–146.

[320] *Cambridge University Calendar 1909–10*, pp.229–251. Only one did not gain mathematical honours: as the son of a peer, Lord A. Hervey was exempt from the Tripos examinations. In 1830 he gained sixth place among those awarded a First Class in the Classical Tripos, and later became Bishop of Bath and Wells.

Britain and fifteen overseas. The overseas bishops covered much of the world: Melbourne, Sydney, Newcastle and Tasmania in Australia; Auckland in New Zealand; Grahamstown, Natal, “Central Africa” and Sierra Leone in Africa; Madras and Calcutta in India; Rangoon in Burma (now Myanmar); Trinidad in the Caribbean; “Mid-China” in the Far East; and Honolulu in the Pacific.

This was a time of rapid expansion of the Anglican Church overseas. Towards the end of the eighteenth century, the Evangelical wing of the established Church took a belated interest in missionary activity in the Colonies, particularly India, Africa and the Caribbean, which had previously been pioneered by Methodists and Baptists. The bishopric of Calcutta was established in 1814; those of Jamaica and Barbados in 1834; and the first Australian bishop was appointed in 1836. A Colonial Bishoprics Fund was founded in 1841, and a large donation of 1847 led to new sees in Australia and the first in southern Africa, at Cape Town. Appointed to Cape Town was Robert Gray, an Oxford graduate, who features below.

In 1853, two further African bishoprics were created at Grahamstown and at Natal. Three of our wranglers were involved in these two appointments: John William Colenso (2nd, 1836) was appointed at Natal; Harvey Goodwin (2nd, 1840) turned down that at Grahamstown; and, three years later, Henry Cotterill (1st, 1835) was appointed there, having already served for ten years as a chaplain at Madras in India. Then, in 1861, Charles Frederick Mackenzie (2nd, 1848) was appointed the first Missionary Bishop of Central Africa. Also in India was John Henry Pratt (3rd, 1833), for many years the Archdeacon of Calcutta.[321]

The Anglican Church, never cohesive, was riven with factions having differing agendas. Relations with dissenters and with the Roman Catholic Church were never easy. High and low church factions squabbled about the conduct of the liturgy. Whereas Cambridge mostly tended towards the Evangelical wing of the Church, then more liberal and tolerant, Oxford went in the opposite direction, where the high-church Tractarian (or Oxford) Movement advocated rigid church discipline and strict adherence to the liturgy. One of the Oxford Movement’s leading lights, John Henry Newman, caused a furore by converting to Catholicism and later becoming a Roman Catholic bishop and cardinal. At the opposite extreme, Charles Simeon was a celebrated Evangelical, who ministered at Cambridge’s University Church of the Holy Trinity for fifty-three years, until 1836.

[321] Goodwin is discussed in Chapter 8 and the others in Chapter 10.

Of particular relevance to the present work is the protracted debate on "science and religion". How did theologians react to new scientific discoveries that raised large questions over traditional interpretations of the Bible? And how did the scientists, themselves mostly devout Christians, engage in the debate? Many of our wranglers were prominent participants: they include Hopkins, Pratt, Birks, Colenso, Goodwin, Cotterill, Stokes, Thomson and Tait, and their involvement is discussed later. First, it is necessary to sketch the origins of the controversy.

All students at Cambridge then studied Paley's *Evidences of Christianity*, first published in 1794, which laid emphasis on miracles as evidence of Divine intervention. And most of the general population believed, and were encouraged to believe, in the literal truth of the Bible. Many accepted the whole work as divinely inspired—even in translation—and so free from all error. But astronomy had long since discredited the Biblical description of the Earth as the fixed centre of the Universe (though then still the official view of the Roman Catholic Church); and geological evidence for the extreme age of the Earth made the Biblical estimate of a mere six thousand years untenable. Though estimates of the age of the Earth still varied greatly, all were in millions, not thousands, of years. Another great challenge came around 1860, with the work of Darwin and Wallace on evolutionary biology, which impinged on the nature of life and the development of mankind itself.

The theological arguments were explored in a collection of seven long *Essays and Reviews* (Temple *et al.* 1860) by Frederick Temple, Rowland Williams, Baden Powell, Henry Bristow Wilson, Charles W. Goodwin, Mark Pattison and Benjamin Jowett. In the words of one modern commentator:

> Controversy, especially religious controversy, was the great spectator sport of Victorian England. . . . *Essays and Reviews* . . . brought to England its first serious exposure to German biblical criticism. It evoked a controversy which included articles in newspapers, magazines and reviews, clerical and episcopal censures, a torrent of tracts, pamphlets and sermons, followed by weightier tomes . . . , prosecution in the ecclesiastical courts, appeal to the highest court, condemnation by the Convocation of the clergy, a debate in Parliament. . . . The controversy lasted four years, drawing on the resources of church and state, representing a crisis of faith contemporary with that provoked by Darwin's *Origin of Species* but more central to the religious mind, indeed 'the greatest religious crisis of the Victorian age.'[322]

[322] Altholz (1994), p.1, quoting Ellis (1980), p.ix. *Essays and Reviews* and its aftermath have been comprehensively examined by these two writers.

In his essay *On the Interpretation of Scripture*, Benjamin Jowett, the Regius Professor of Greek at Oxford, chided theologians for failing to apply the same philological rigour to Biblical texts as was routinely employed to classical works. He warned against the dangers of preachers who wish "to awaken not so much the intellect as the heart and conscience", and overstep the limits of their knowledge in interpreting Scripture. Regarding those contested "scientific facts with which popular opinions on theology often conflict", it is "a false policy to set up inspiration and revelation in opposition to them. . . . Shall we peril religion on the possibility of their untruth?" The meaning of Scripture, often obscure, had been interpreted, often anachronistically, by each Christian faith in accordance with its own beliefs. But "Scripture has one meaning—the meaning which it had to the mind of the prophet or evangelist who first uttered or wrote, to the hearers or readers who first received it." Accordingly, it should not be expected that the Bible accurately represents physical facts unknown at that time. Controversies would come and go: while some still raged, "A silence is observable on some other points of doctrine around which controversies swarmed a generation ago."[323]

In his essay entitled *On the Study of the Evidences of Christianity*, Oxford's Savilian Professor of Geometry, Baden Powell, contested the place of miracles as signs of Divine Revelation. The evidence for many supposed miracles was slight and attributable to credulous witnesses or even fraud: though many had been attested to in the past, few had been reported in modern times. Though some recorded events could not be explained by known laws, this was not necessarily evidence for the temporary suspension of these laws by a supernatural agent. For many, belief in miracles followed as a *result* of belief in an Omnipotent God; but others who supported the idea of Divine perfection rejected this idea of occasional intervention, the world being supposed perfect at the outset. Still others supposed that all of nature was a continuing miracle, maintained by Divine action "like a mill, which cannot go on without continual application of a moving power!" With such uncertainty, the "evidence of miracles" should be assigned a much lower place than "the conviction of real faith."[324]

Astronomy, geology, and most recently, evidence for "the antiquity of the human race, and the development of species" had forced a dissociation of the spiritual from the physical: they were in clear contradiction to literal interpretation of Scripture. Baden Powell is unequivocal in his enthusiasm for "Mr. Darwin's masterly volume on *The Origin of Species* by the law of 'natural

[323] Temple *et al.* (1860), quotations from pp.333, 349, 378, 422.

[324] Temple *et al.* (1860), pp.106–114, 126, 135.

selection' . . . : a work which must soon bring about an entire revolution of opinion in favour of the grand principle of the self-evolving powers of nature." And he goes on to criticise a theory of civilization by Archbishop Whately, who had proposed that "the use of fire, the cultivation of the soil and the like, were Divine revelations" to primitive peoples. Baden Powell countered that, if this was the case, so also must be printing and steam in recent times; and, if the boomerang was divinely communicated, so too must have been the gyroscope.[325]

Charles Wycliffe Goodwin's essay *On the Mosaic Cosmogony* addressed the creation story of the book of Genesis in the light of modern science. Genesis plainly said that the Universe was created in six days with a fixed Earth at its centre, a view that was no longer tenable. Goodwin suggests that: "It would have been well if theologians had made up their minds to accept frankly the principle that those things for the discovery of which man has faculties specially provided are not fit objects of a divine revelation." But theologians had instead attempted to rescue the Biblical version of creation by interpretations and equivocations such that: "The plain meaning of the Hebrew record is unscrupulously tampered with, and in general the pith of the whole process lies in divesting the text of all meaning whatever." It was evident on philological grounds that Genesis gave two distinct accounts of creation: that of the first chapter and the first three verses of the second was clearly by a different hand than the version given in the second chapter from verse four onwards. The former was clear and precise in its statements, allowing no mystical or symbolical meaning; whereas the second gave "at least some ground for the supposition that a mystical interpretation was intended to be given to it."[326]

Recent defences of the Genesis accounts had been given by the Scottish theologian Thomas Chalmers, and by William Buckland, Oxford fellow, geologist and dean of Westminster. Their cases were built on taking the six biblical "days" of creation to be preceded and separated by vast periods of time, and on implausible reinterpretations of perfectly clear Biblical statements. As for Buckland's view that the object of the Biblical account was "not to state in *what manner*, but *by whom* the world was made", Goodwin objects that it was incredible that the writer had no intention that his words should be taken

[325] Temple *et al.* (1860), pp.129, 139–141.

[326] Temple *et al.* (1860), pp.209–211, 223. C.W. Goodwin was the Egyptologist brother of Harvey Goodwin (2nd, 1840), who features in Chapter 8. He had attended St Catharine's College, Cambridge, graduating in 1838 as ninth senior optime in the Mathematical Tripos and with a first class in the Classical Tripos.

literally. Other geologists had proposed an "entirely mythical and enigmatical sense to the Mosaic narrative"; and some theologians and geologists supported the view that the "days" of creation might themselves be periods of indefinite length.[327]

John Henry Pratt, the Archdeacon of Calcutta, had already weighed in with criticisms of even this last interpretation, which did not accord with what he believed to be the appearance of several distinct periods of animal and vegetable existence. And similar objections had been raised by the Scottish geologist Hugh Millar. In Goodwin's view, the theories of Buckland, Pratt and Miller "divest the Mosaic narrative of real accordance with fact." The upholders of each theory had evaded "the plain meaning of language, to introduce obscurity into one of the simplest stories ever told, for the sake of making it accord with the complex system of the Universe which modern science has unfolded." Goodwin concludes that the "consistency and grandeur" of the Mosaic account "may be preserved if we recognise in it, not an authentic utterance of Divine knowledge, but a human utterance, which it has pleased Providence to use in a special way for the education of mankind."[328]

The resulting controversy gripped the nation. Among the first attempts to refute *Essays and Reviews* was T.R. Birks' (2nd, 1834) *The Bible and Modern Thought*; and J.H. Pratt prepared several new editions of his book to disagree with *Essays and Reviews* and with later unorthodox writings.[329] One of the essayists, Rowland Williams, was prosecuted for heresy; and so too would have been Baden Powell, but for his death soon after his essay appeared. Another furore soon followed over the writings of J.W. Colenso: this is discussed in Chapter 10. But, gradually, theologians were forced to change and refine their positions, first to regard not *all* the Bible, but only those parts directly concerned with doctrine, as a Revelation from God that should be beyond question; and then to accept that the Bible is a mixture of theology, poetry and history in which the Genesis stories should be interpreted figuratively rather than literally. Through such reinterpretations, "the heresies of the Essayists later became acceptable, then commonplace, then *passé*."[330]

---

[327] Temple *et al.* (1860), p.236.

[328] Temple *et al.* (1860), pp.237, 250, 253; Pratt (1856). On Pratt, see also Chapter 10, pp.255–258.

[329] Birks (1861), Pratt (1856) and later editions to 1872.

[330] Altholz (1994), p.2. The collision of geology and theology is examined by Gillispie (1951), and there is a huge modern literature on the impact of Darwinism. For a recent account of the ongoing science–faith debate, see e.g. Alexander (2001).

8.

Wranglers at Home: Four Biographies

As illustrations of the diverse lives of the wranglers, we first discuss three scientists and one divine whose careers were spent in England. The largely self-educated George Green, the mathematical astronomer John Couch Adams, and the mathematical physicist George Gabriel Stokes are famous for their contributions to science. But Stokes was also a leading Anglican, who shared many of the preoccupations of our fourth subject, the scientifically trained divine Harvey Goodwin, regarding the connections and conflicts between science and religion.

As already stated, attention is not now confined to individuals known to have been tutored by William Hopkins. Of the four, only Stokes and Goodwin were Hopkins' students; but Hopkins took an interest in the mature student Green and may well have given him informal advice. Adams seems to have had no direct contact with Hopkins, being tutored mainly by John Hymers of St John's College. Green features here because of his unusual background and his key place in the evolution of Cambridge mathematical physics, though he held a junior fellowship for only a short time. Stokes and Adams were the first two wranglers of what may be termed the "Hopkins era" to become Cambridge professors in mathematical subjects, and both did work of great distinction. And Goodwin was a fellow and mathematical tutor for a time, before attaining high positions in the Anglican Church.

In the following Chapter 9, we sketch more briefly the careers of many other wranglers who were employed in British and Irish universities and colleges. Then Chapter 10 concerns those who chose very different lives abroad in the colonies, as educators, churchmen and missionaries.

George Green

George Green could hardly have been more different from the typical Cambridge undergraduate of his day. After little formal education, he enrolled as an undergraduate at Caius College in 1833 at the advanced age of forty; and he died a mere seven-and-a-half years later on 31 May 1841. Yet he is rightly regarded as one of the finest mathematical scientists of his time.

Green was born in Nottingham on or just before 14 July 1793 (the date of his baptism). His father, also named George, was a successful and enterprising Nottingham baker, who gradually acquired property for rent in the growing town. Around 1807, at nearby Sneinton, he built a wind-driven corn-mill which supplied flour for the bakery; and, in 1817, he built a family house next to the mill. George junior attended the academy of one Robert Goodacre for little more than a year, during 1801–02, and then went to work in the bakery at the age of nine. Later, he worked at the mill under its manager, William Smith. The mill was one of the first of its kind in the county, and is now restored as a museum, known as "Green's Mill".[331]

Figure 8. The restored Green's Mill, at Sneinton, Nottingham. (Courtesy of Nottingham City Museums and Art Galleries.)

[331] Much, though not all, of the information below is also in Cannell (2001), the best biography of Green.

Somehow, Green acquired an interest in mathematics and physics, and soon reached an impressive level of knowledge by private study in his spare time. He learned enough French and mathematics to study the foremost French writers: principally Arago, Laplace, Lagrange, Fourier, Cauchy, Lacroix, Poisson and Biot. He read not only French treatises, but also the *Mémoires* of the Academy of Sciences in Paris. These works were not to be found in Nottingham bookshops or libraries, and it is not known how he acquired copies of them.

Though no definite evidence has been found, it has been plausibly conjectured that he received encouragement from the Rev. John Toplis, who had studied at Queens' College, Cambridge, and who was headmaster of the Free Grammar School in Nottingham during 1806–19. Toplis had been eleventh wrangler in 1801 and was one of the first to urge British mathematicians to adopt the new style of French analysis. To this end, his translation of the first volume of Laplace's *Mécanique Céleste* was published in Nottingham in 1814, and this would surely have been known to Green. In 1819, Toplis returned to Cambridge as the Dean of his old college.[332]

Green formed a long-lasting liaison with Jane Smith, the daughter of the mill manager, and their first child was born in 1824. Although the two never married, and apparently rarely lived together until Green's final illness, they had a total of seven children, all but the first baptised with the surname of Green. It is said that George Green senior disapproved of the liaison: Jane Smith worked as a lace dresser and, as the daughter of an employee, would have seemed an unworthy match. Green's biographer, Mary Cannell, suggests that George senior may have threatened to disinherit his son if they married. When George senior died in 1829, George junior inherited the mill and property, but no marriage took place.

In March 1828, Green's first, and most important, work was published privately. A small print run was supported by just fifty-one subscribers, who mostly lived locally and, like Green, were members of the Nottingham Subscription Library. Few of the subscribers would have understood much of Green's seventy-two-page *Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism* (Green 1828), and the book's existence was hardly noticed in scientific circles. Only after his father's death in the following year could George Green adopt the lifestyle of a "gentleman": renting out the mill, he at last had ample time for mathematics.

One of the subscribers to Green's *Essay* was Sir Edward ffrench Bromhead, whose Lincolnshire country estate was nearby. Bromhead had been a

[332] See Chapter 4, pp.60, 61, and Guicciardini (1989), Cannell (2001).

contemporary of Babbage, Herschel and Peacock at Cambridge, and one of the undergraduate Analytical Society that promoted the continental calculus. Though an able mathematician, Bromhead, like Babbage, was not a wrangler: he had delicate health and, as a wealthy aristocrat, he would not have considered the effort required to gain a high Tripos place as worth his trouble. Even if he did not understand all of Green's *Essay*, Bromhead certainly knew enough to conclude that Green was an excellent mathematician deserving of support. He immediately offered to communicate any other writings by Green to the Royal Societies of London or Edinburgh, or to the Cambridge Philosophical Society, of each of which he was a fellow. After some delay, Green obliged with three papers, two eventually appearing in the *Transactions of the Cambridge Philosophical Society* and one in the *Proceedings of the Royal Society of Edinburgh*.[333]

At this time, Green was already a formidable mathematician, but he was still learning the craft of writing: the style of his *Essay* and of his early papers, and especially his first few awkwardly verbose letters to Bromhead, contrast with the conciseness and precision of his later writing. Condensation of his first Cambridge paper was necessary before its acceptance by the editor, William Whewell. This paper, sixty-three pages long even after pruning, concerns "the laws of the equilibrium of fluids analogous to the electrical fluid", under rather general assumptions of the mutual repulsion of its particles. The second Cambridge paper, which also suffered delay in publication, dealt with the already much-worked-on problem of the gravitational attraction of ellipsoids. Again striving for generality, Green needlessly allows space to be *n*-dimensional, rather than three-dimensional. The Edinburgh paper addressed a topic in hydrodynamics, the periodic vibration in air of an arbitrarily oriented pendulum bob with ellipsoidal shape; and publication of this, too, was delayed for nearly three years after its acceptance. This impressive paper, though restricted to very small oscillations, was the first to demonstrate the change in frequency attributable to the "added mass" effect of the moving air. As this effect is very small, and the viscosity of air was neglected, Green did not rate this work highly, later confiding to Bromhead that "the paper is a rather unimportant one."[334]

As early as 1830, Bromhead had suggested that Green consider studying in Cambridge. In April 1833, Green wrote to Bromhead that: "you are aware that I have an inclination for Cambridge if there is a fair prospect of success. Unfortunately, I possess little Latin, less Greek, have seen too many winters,

333 Green (1833; 1835; 1836).

334 Cannell (2001), p.94, citing Green's letter of May 1834.

and am thus held in a state of suspense by counteracting motives." In June of the same year, Bromhead invited Green to accompany him on a visit to Cambridge, offering to introduce him to Herschel, Babbage and others. But Green diffidently declined: "Being as yet only a beginner I think I have no right to go there and must defer the pleasure until I have become tolerably respectable as a man of science should that day ever arrive." Soon after, Green took the big decision, and, in October 1833 at the age of forty, he enrolled at Gonville and Caius College, where Bromhead had formerly studied.[335]

Though he paid fees during his first term, and was able to afford more comfortable accommodation in college than some students had to endure, Green was soon awarded a scholarship that he held for the remainder of his time as an undergraduate. The mathematical syllabus presented Green with no difficulties, unlike the Latin and Greek which he also had to study in his first year. He was widely tipped as the betting favourite for senior wrangler in the Tripos of 1837; but he did not meet these high expectations, and was awarded only fourth place. As an already mature mathematician, he must have lacked the inclination to memorise theorems and proofs of Euclid, and those other elementary topics on which top candidates could amass many marks. Instead of preparing single-mindedly for the examinations, he was pursuing his own researches and preparing papers for publication.

There is no evidence that Green ever studied with a private tutor for mathematics. Late in life, William Thomson asserted that "Green was never a pupil of Hopkins."[336] However, Hopkins possessed not one but several copies of Green's *Essay*, at a time when the work was virtually unknown, and the two men certainly knew each other. It seems unlikely that Hopkins would have bought *several* copies of Green's *Essay*, for electricity and magnetism were not then much taught. Did Hopkins give Green some informal advice or tuition, to be rewarded by this gift from Green? The senior wrangler of Green's year, W.N. Griffin, was a pupil of Hopkins, and the second wrangler, J.J. Sylvester, also studied briefly with him. Neither Griffin nor the third wrangler, E. Brummel, made any later mathematical contributions of substance, but Green, Sylvester and the fifth and sixth wranglers, D.F. Gregory and A.J. Ellis, all left their marks. Yet it was Griffin and Brummel who were awarded the first and second Smith's Prizes.

Hopkins and Green had several things in common. They were born in the same year, and both had worked at uncongenial labours before attending

[335] Cannell (2001), pp.83, 84.

[336] Cannell (2001), p.143: Kelvin to Joseph Larmor, 19 Nov. 1907.

university, Hopkins as farmer and Green as baker and miller. While the young Green worked in Nottingham, Hopkins was only a few miles away, farming in Derbyshire. Both entered Cambridge as mature students, Hopkins aged twenty-nine and Green aged forty. But the straight-laced Hopkins would surely have disapproved of Green's personal life, had he known about it.

In 1834, Green expressed concern to Bromhead that, though his second Cambridge paper had been read (and so accepted) some months before he was admitted to the University, it might be refused publication now that he had become an undergraduate. But it duly appeared in 1835, perhaps the first paper by an undergraduate in the *Transactions of the Cambridge Philosophical Society*. All Green's remaining papers were submitted to the same journal. Three were read in 1837 (the year of his graduation) and published in the following year, and the remaining three were read and published in 1839. Two are on water waves in canals, two on the propagation of light in crystallised and non-crystallised media, and one on the closely related topic of reflection and refraction of sound.[337]

When he sent his Edinburgh paper to Bromhead in February 1833, Green informed him that its results agreed with some unpublished calculations "relative to the motion of fluids written many years ago at such intervals of leisure as I could snatch from other avocations." Because Green's manuscripts have not survived, it is impossible to know how far his researches on hydrodynamics progressed before he went to Cambridge; but it is likely that he had read the difficult works of Lagrange, Poisson and Cauchy on water waves. Green's first paper on water waves, published in 1838, may well originate from this early period; but his second paper of 1839 was prompted by recently reported experiments of John Scott Russell. His groundbreaking papers on sound and light, as vibrations of elastic media, may also be distilled from earlier studies: his references to Poisson, Cauchy, Lagrange and Airy were to works that were (somehow) available to him in Nottingham. John Venn's statement in the *Biographical History of Gonville & Caius College*, that "His mathematical work was almost all done before graduation" may well be true.[338]

Green was elected a fellow of the Cambridge Philosophical Society in November 1837. Just over a year later, Hopkins wrote enthusiastically to J.D. Forbes that

[337] Green's list of publications is in Cannell (2001), p.99, and all are reprinted in Ferrers (1871), the latter now also available in a modern Dover reprint.

[338] Quotations from Cannell (2001), pp.81, 88.

> we have lately had an admirable paper by Green in which he deduced expressions for the intensities of the reflected and refracted rays agreeing in essential points with Fresnel's, and without any particular assumptions as to the molecular constitution of the refracting medium. It is the only paper in my opinion which has hitherto with any certainty touched the real physique of the question.[339]

Green stayed on in Cambridge, but he had to wait until October 1839 until he was elected to a Perse Junior Fellowship at Caius, worth a mere £10 a year. In contrast, the twelve senior fellows of the college received far more substantial remuneration. And another fellow, Robert Murphy, spectacularly failed to make ends meet, despite his promotion in 1838 to a Stokes Fellowship worth £95 per half-year.

The son of a cobbler from Mallow in Ireland's county Cork, Murphy was a first-class mathematician. But for his mismanaged personal life, ruined by alcohol and gambling, he could and should have done much more. His "dissipated habits" and debts led to his departure from Cambridge in 1836, though he may have returned occasionally. Accordingly, there is some doubt as to whether he and Green ever met: if they did so, it is most likely to have been while Green was still an undergraduate. Murphy's book on electricity, published in 1833, and his other fine mathematical work perhaps made him "the only mathematician of stature in Caius, and possibly in Cambridge, with whom Green could readily associate."[340] Green may well have sought him out to give him a copy of his *Essay*, for Murphy refers to it in a paper of 1835 on indefinite integrals.[341] But Murphy could also have seen the copy that Green presented to Caius College Library. Because Murphy's reference comes in a footnote, it was probably added after his paper was read in November 1833, just a month after Green's first enrollment.

The Irishman Matthew O'Brien (3rd, 1838) also overlapped with Green at Caius College, and was briefly a fellow in 1840–41. They certainly met, and O'Brien refers in complimentary terms to two of Green's papers in one of his own.[342] There is no evidence that Green interacted with his exact contemporaries J.J. Sylvester or D.F. Gregory, who were at different colleges. The only other scientist to whom he is known to have communicated his work is, surprisingly, Carl Jacobi of Königsberg, who received copies of six of Green's

---

339 Hopkins (ms.1839).

340 Cannell (2001), pp.112, 113.

341 Murphy (1835).

342 O'Brien (1842).

papers, perhaps by request. Green's biographer, Mary Cannell, speculates that, after his intellectual isolation in Nottingham, Green found little more stimulus in Cambridge:

> He was perhaps almost as intellectually isolated as he had been in the 1820s, and apart possibly from Murphy, with no access to a mathematical intellect to match his own. Perhaps he found companionship in the company of Hopkins. . . .

But Whewell, soon to be Master of Trinity, would have remained aloof.[343]

The notorious Caius College Wager Book of the Fellows' Combination Room records many bets of bottles of wine, purchased by the losers for common consumption: this clearly records Murphy's time in residence and his inveterate gambling. It also bears several signatures of Green, O'Brien and W.H. Stokes (a brother of G.G. Stokes). In 1833, Murphy and six other fellows donated six bottles to celebrate the achievement of Alexander Ellice of Caius in becoming senior wrangler. Green's name first appears as a guest in November 1837, shortly after his election to the Cambridge Philosophical Society, and then on several other occasions up to March 1840.[344]

In the spring of 1840, Green returned to Nottingham in ill health, believing that he would not recover. He remained there in the care of Jane Smith and surrounded by their children, the seventh and last, Clara, born shortly after his return. He died just over a year later, on 31 May 1841 at the age of forty-seven, the cause given as influenza. It has been suggested that he had contracted a progressive pulmonary disease, perhaps "miller's disease" or tuberculosis. But he had apparently enjoyed excellent health before going to Cambridge, and some have concluded that, like Murphy, he succumbed to an excess of alcohol. He was proud of his fellowship, though he held it for so short a time. He was buried with his parents at St. Stephen's churchyard, Nottingham, and is described on the gravestone as "George Green Esq., B.A. Fellow of Caius College, Cambridge".[345]

Once embarked on his Cambridge career, Green would not have wished to regularise his liaison with Jane Smith, because marriage would have debarred him from a fellowship. But, in his will, George Green provided well for her and their children, dividing among them the ownership of his substantial property. Jane Smith was known locally as "Mrs. Jane Green", and seems to

343 Cannell (2001), pp.104, 115.

344 Cannell (2001), pp.108, 109.

345 Cannell (2001), pp.115, 116.

have been well respected by those who knew her: on her death in 1877, she was buried in a plot next to the Greens.[346]

Green's published work remained relatively little known in his lifetime: the *Essay*, in particular, was almost completely disregarded. Writing to J.D. Forbes in 1856, Humphrey Lloyd of Dublin opined that "Green's optical researches are much less known than they deserved. Had he lived, he would, I believe, have done more for this branch of Science than any of the successors[?] of Fresnel."[347] But Green's papers on light and on hydrodynamics were to provide key stimuli for George Gabriel Stokes: even the clear style of Stokes' mathematical exposition is reminiscent of Green's later papers. And it was almost certainly Hopkins who first drew the attention of the young Stokes to them.

The assessment by the eminent authority, Sir Edmund Whittaker, first written in 1910 and repeated in 1951, deserves quotation:

> It is impossible to avoid noticing throughout all of Kelvin's [William Thomson's] work evidences of the deep impression which was made upon him by the writings of Green. The same may be said of Kelvin's friend and contemporary Stokes; and, indeed, it is no exaggeration to describe Green as the real founder of the "Cambridge school" of natural philosophers, of which Kelvin, Stokes, Rayleigh, Clerk Maxwell, Lamb, J.J. Thomson, Larmor and Love were the most illustrious members in the latter half of the nineteenth century. . . .
>
> The century which elapsed between the death of Newton and the scientific activity of Green was the darkest in the history of the University. . . .
>
> A few years before Green published his first paper a notable revival of mathematical learning swept over the University . . . and the works of the great French analysts were introduced and eagerly read. Green undoubtedly received his own inspiration from this source, chiefly through Poisson; but in clearness of physical insight and conciseness of exposition he far excelled his masters; and the slight volume of his collected papers has to this day a charm which is wanting in their voluminous writings.[348]

346 But several of the children suffered on account of their illegitimacy. The eldest son, also George, had some talent for mathematics and enrolled at St John's College, Cambridge at the rather advanced age of twenty-six. He was disappointed not to become a wrangler, being third senior optime. For a time he worked as a tutor, but committed suicide at the age of thirty-nine. Cannell (2001, pp.124–128).

347 Lloyd (ms.1856).

348 Whittaker (1951), p.153.

It was William Thomson who rediscovered and promoted Green's *Essay*. He had long been looking for it, having seen the reference in Murphy's 1833 paper on integrals (though he presumably did not look in Caius College Library). Shortly after completing his Tripos examinations in January 1845, Thomson mentioned his search to Hopkins, who informed him that he had several copies, and gave him two. Thomson was impressed by what he read, writing in his diary that it "renders a separate thesis on electricity less necessary" than he had thought. Soon after, Thomson departed for Paris, where he showed Green's *Essay* to the prominent mathematicians Joseph Liouville, Charles-François Sturm and Michel Chasles. All were surprised to find that it had anticipated some of their own results. The German August Crelle immediately offered to republish it in his *Journal für die Reine und Angewandte Mathematik*, with a short introduction by Thomson. It appeared in three parts during 1850–54. Later, it was republished by Gonville and Caius College in the *Mathematical Papers of George Green*, edited by N.M. Ferrers (1871), with a short introduction by Ferrers that is discreetly silent about Green's private life. A German translation of the *Essay* appeared in 1895, and a fine facsimile of the original edition was produced in Sweden in 1958. The importance of Green's earliest work was at last appreciated worldwide.[349]

The *Essay* has several sections. After a few "Introductory Observations" that cite mainly French sources but also Henry Cavendish and Thomas Young, Green presents his "General Preliminary Results". The most important is now known as *Green's Theorem*, a fundamental result connecting integrals involving two arbitrary continuous functions of the three spatial coordinates x, y and z. This he later generalises to include functions that possess singularities at particular points in space. Green's statement of his theorem is given in Appendix A, pp.355, 356.

The *Essay* continues with two long sections, on electrostatics ("The Theory of Electricity") and magnetostatics ("The Theory of Magnetism") respectively, that repeatedly use the mathematical results derived in the earlier section. In these, Green employs the concept of a *potential function* from which the components of force can immediately be derived by differentiations along each coordinate direction; and he develops his method for solving certain inhomogeneous partial differential equations by means of *Green's functions*, as they are now called.

Green's fundamental theorems, his early applications of potential theory to electrical and magnetic phenomena, and his method of Green's functions

349 Cannell (2001), pp.143, 144, 148–150, 299; Thompson (1910), v.1, 114–118.

together establish the *Essay* as a milestone of the mathematical sciences, pointing the way to many later advances. Yet it remained practically unnoticed, until rediscovered by William Thomson seventeen years after its publication and four years after Green's death.

Green the man remains elusive, his motivations rather unclear. He was described as of a "reserved disposition"; and his brother-in-law recorded that he had "in youth a frail constitution", and found the work assisting his father "irksome", preferring to study mathematics.[350] His early letters to Bromhead show him socially ill-at-ease, unsure how to respond to the aristocratic Bromhead's offers of assistance. No portrait of Green is known to have survived.

His acquisition of specialised French texts has already been mentioned. But what drew him to science and mathematics? There is no evidence that he ever performed his own experiments or observations, unless one counts the not inconsiderable practical mechanics involved in working the windmill. But he paid close attention to descriptions of the experiments of Cavendish, Arago, Coulomb and Biot, as well as to the more mathematical French writings that inspired him. Robert Goodacre's school prospectus mentions various scientific instruments, including an electrical machine and an air pump. Did these first arouse Green's interest? Or was John Toplis the key figure of his youth?

Public recognition for Green's achievements was finally achieved in 1985, with the opening in Nottingham of Green's Mill and Science Centre. The 1993 bicentenary of his birth was an occasion for further ceremony and celebration, including the laying of a commemorative plaque in Westminster Abbey. Appropriately, this is close to Isaac Newton's memorial, to a commemorative wall medallion for Stokes, and to plaques in honour of Faraday, Clerk Maxwell and Lord Kelvin.[351]

John Couch Adams

John Couch Adams' tutor at St John's College was John Hymers, the second wrangler of 1826.[352] Adams was one of the most illustrious mathematical astronomers of his age, and a participant in one of the great scientific *causes célèbres* of the nineteenth century. The furore in which he was involved sheds

350 Cannell (2001), pp.47, 207.

351 Cannell (2001), Ch.11.

352 Warwick (2003), p.86n.

an interesting, and far from complimentary, light on the conduct of the Cambridge, and indeed British, scientific establishment.[353]

Adams was born at Lidcot, near Launceston in Cornwall, on 5 June 1819, the son of a tenant farmer and the oldest of seven children. He attended the village school at nearby Laneast, and then a private school at Devonport run by an older cousin. But Professor James Challis described him as having been largely self-taught, with assistance from the Rev. George Martin, formerly Principal of a training college in Exeter.[354]

Adams' aptitude for mathematics was evident from an early age, and he soon became interested in astronomy. Aged only sixteen, he computed the details of an annular solar eclipse as seen from Lidcot. In 1834 he received, as a prize, Sir John Herschel's recently published *A Treatise on Astronomy* (1833), a volume of Lardner's *Cabinet Cyclopaedia*. This turned out to be a singularly apt choice. Sir John Herschel's father, Sir William Herschel, had been a professional musician and music teacher in Bath; and he pursued his hobby of astronomy to such effect that he constructed the most powerful telescopes yet known. In 1781, William observed what he at first thought was a strange comet, but which was soon realised to be something even better: a new planet, eventually named Uranus. The discovery earned William a knighthood and royal patronage. In just a few years, Adams was to emulate William Herschel as the co-discoverer of Neptune, the next planet to be found.

In 1839 Adams entered St John's College, Cambridge as a poor sizar, as his family had little money to spare for his education. In 1841, he bought a copy of George Biddell Airy's recent "Report on the Progress in Astronomy", delivered to the British Association for the Advancement of Science. In this, Airy pointed out some small but curious deviations of the orbit of Uranus from its predicted orbit. Adams was fascinated, and recorded his intentions in a memorandum dated 3 July 1841:

> Formed a design in the beginning of this week, of investigating, as soon as possible after taking my degree, the irregularities in the motion of Uranus, which are yet unaccounted for; in order to find whether they may be attributed to the motion of an undiscovered planet beyond it, and if possible thence to determine the elements of its orbit, etc. approximately, which would probably lead to its discovery.[355]

---

353 Adams' story is told at greater length in Glaisher (1896), Jones (1947) and Standage (2000).

354 Hutchins (2004); Challis (ms.1854).

355 This memorandum, discovered among Adams' papers after his death, is reproduced in full in Jones (1947), pp.11, 12.

But, in order to concentrate on the Tripos, he deliberately suppressed his passion for astronomy, thereby losing a year and a half of time which was more pressing than he knew. When he graduated as senior wrangler in 1843, he was said to be so far ahead of his rivals that he had amassed twice as many marks as the second wrangler.[356]

The best tables of Uranus' predicted position had been calculated during the 1820s by the Frenchman, Alexis Bouvard; but during the 1830s these deviated more and more from the true position. By 1841, the error was 70 arcseconds, or just over 1/60th of a degree. Though this may seem tiny (the Moon's diameter subtends half of a degree), in the precise world of planetary astronomy this is a substantial deviation. At first, it was believed that the deviation was entirely attributable to the gravitational attraction of the neighbouring, and particularly massive, planets of Jupiter and Saturn. Although Bouvard had attempted to incorporate their effects, there were doubts about the accuracy of his calculations. Adams recalculated the influences of Jupiter and Saturn, and found that they alone could not account for the discrepancies. He became convinced of the truth of the conjecture already circulating, that there must be another undiscovered planet beyond the orbit of Uranus.

The problem of predicting the position, orbit and mass of an unknown planet from evidence of its perturbations upon the orbit of a neighbouring one had never been attempted before. The leading theoretical astronomers of the day, among them Airy, considered the task impossible. But, without such a prediction, the astronomers did not know where to point their telescopes to find it; and the chances of a lucky find, like William Herschel's of Uranus, were minuscule. Indeed, many thought that such a distant planet might be too faint to be seen through even the largest of telescopes.

Adams set to work on the problem during the summer of 1843, when back home at Lidcot. He first indulged in some intelligent guesswork about the likely distance and mass of the unknown planet; and, as a first approximation, he supposed that its orbit around the Sun was circular rather than elliptical. Even then, the calculation was formidably complicated; but the results confirmed Adams' belief that the unexplained deviations of Uranus were consistent with the presence of a new planet, orbiting at a distance from the Sun about twice that of Uranus.

The orbital period of Uranus is about eighty-four years, and that of the conjectured planet was thought to be a little over two hundred years (in fact its period is nearly one hundred sixty-five years, for the mean radius of its orbit is less than was supposed). Accordingly, for much of the time, the planets

---

356 Standage (2000), p.68.

are far distant from one another; and for only about thirty years of each 165-year period is their mutual influence significant. Importantly, 1810–40 was one of these periods.

Back in Cambridge, Adams became immersed in other duties; but he sought the help of James Challis in obtaining more observational data on Uranus. Such data were held by Airy at the Royal Observatory at Greenwich, and Challis wrote to Airy, on behalf of a "young friend of mine, Mr Adams, of St John's College [who] is working at the theory of Uranus." Airy replied immediately, sending all the relevant data; and, as soon as he found time, Adams started on a more detailed analysis, this time supposing the unknown planet to have an elliptical orbit. He reduced his problem to a set of twenty-one linear algebraic equations: these expressed the known (but perhaps slightly inaccurate) discrepancies at twenty-one different times, in terms of eighteen unknown constants related to the properties of the supposed planet. To minimise the effect of inaccuracies in his data, and to yield a system with a unique mathematical solution, Adams then applied the method of least squares of Legendre and Gauss. In September 1845, the eighteen constants were thereby determined, and Adams was able to predict the position of the unknown planet for 1 October 1845.

In June 1845, Adams had attended the British Association for the Advancement of Science which met in Cambridge. But, being too diffident, he missed the opportunity to introduce himself to both Airy and John Herschel. Now, in September, with his prediction in hand, Adams resolved to visit Airy to ask him to look for the planet. Equipped with a letter of introduction from Challis, but without taking the precaution of making an appointment, Adams arrived at Greenwich only to discover that Airy was in France. On his return, Airy punctiliously wrote to Challis, asking him to "mention to Mr Adams that I am very much interested with the subject of his investigations, and that I should be delighted to hear of them by letter from him"; but Adams did not reply promptly.

Instead, he made a second attempt to meet Airy on October 21st, again without prior arrangement, and again unsuccessfully. Airy was out when Adams arrived, and, when he called back later in the day, he was turned away by Airy's butler (without Airy's knowledge) because the household was dining early. Adams returned disappointed to Cambridge, leaving behind only a brief note of his findings on a single sheet of paper. His social ineptitude in *twice* arriving without an appointment is hard to understand.

Airy had no means of assessing the reliability of the information in Adams' note, and he probably still believed that a solution to the problem was impossible. Neither he nor Challis thought it worth searching for the supposed planet on such evidence. Airy himself believed that an alternative explanation of the deviations of Uranus might be a small inaccuracy of the inverse-square law of gravitational attraction, discernable only at very large distances from the Sun. In November, Airy replied to Adams' note, asking for further details which could have settled this matter. But Adams had already embarked on a further improvement of his theory, and unwisely decided not to reply to Airy until this was complete.

Meanwhile, at the École Polytechnique in Paris, the astronomer Urbain Jean-Joseph Le Verrier was at work on his own calculations. In 1845 and 1846, he published two papers. In the first, and the first part of the second, he recalculated with great accuracy the influence of Jupiter and Saturn on the orbit of Uranus, and he confirmed that discrepancies with the observed orbit still remained. In the second part of the 1846 paper, he estimated the likely position of a conjectured new planet. With a method rather different from that of Adams, but incorporating a similar assumption about the orbital radius of the assumed new planet, Le Verrier's prediction turned out to be remarkably close to Adams'. Airy quickly learned of these papers, and was impressed by them, as were astronomers throughout Europe. When Airy noticed the similarity of Le Verrier's prediction with that in Adams' note of eight months earlier, he decided that urgent action was necessary.

Airy wrote to William Whewell to inform him that Adams and Le Verrier had obtained very similar results. And he wrote to Le Verrier to ask for the same further details that he had previously sought from Adams, but without informing him of Adams' work. He also told the Board of Visitors of the Royal Observatory, including Herschel and Challis, of "the extreme probability of now discovering a new planet in a very short time."[357]

Le Verrier replied promptly to Airy, answering his queries—which Adams had still not done—and in early July Airy invited Challis to begin an immediate search for the new planet. His choice of Cambridge may have been because Cambridge's Northumberland telescope was larger than any at Greenwich. But Airy also would not have wanted to disrupt the routine work of his own Observatory, which had well-defined duties that did not include searching for new planets; and he may have wished that Cambridge University should receive the honour for discovering the new planet.

Challis, however, remained less than enthusiastic. Though he agreed to gather observational data by night, he continued to work by day on analysing his previous observations of comets. He believed that the predicted position was likely to be only a rough guide, and that data-gathering would be required over a fairly extensive region surrounding it. In short, he saw no need to

[357] Standage (2000), p.92.

analyse his data until he had gathered it all. This was a serious error. If he had promptly compared his data from July 30 and August 12 of 1846, he would have been the first to find the planet, very close to its predicted position.[358]

Then, on August 31 in Paris, Le Verrier presented a third paper at the Académie des Sciences. This gave further details of his calculations and a refined estimate of his predicted position of the missing planet; and he urged astronomers to search for it there. Less publicly, and still ignorant of Le Verrier's work, Adams sent his own revised estimate to Airy just two days later on September 2, some ten months after Airy had asked him for further information. But Adams' bad luck in contacting Airy continued, for Airy was then on an extended visit to Germany. An attempt by Adams to present his results at the meeting of the British Association later that month also came to nothing: he arrived at Southampton a day too late, to find that the section on mathematics and physical science had ended. Around the same time, with Le Verrier's encouragement, an assistant at the Berlin Observatory, Johann Gottfried Galle, began searching for the planet; and on September 24 he found it. The discovery was triumphantly announced, and Le Verrier and Galle rightly received the credit.

Still in ignorance of Galle's discovery, on September 29 William Whewell informed J.D. Forbes that "Challis is busy looking out for a new planet beyond Uranus. Analysis says there must be one. If a new planet comes out of the equations of motion it will be a grand result."[359] As soon as the discovery became known in Britain, belated efforts were made to obtain recognition for Adams' part in the "grand result". With Airy still away in Germany, John Herschel revealed the existence of Adams' unpublished work in a letter to the *Athenaeum*. And Challis at last started to examine his data, announcing in the press that he had been gathering it since July, some months before the planet's discovery by Galle. The French astronomers were naturally upset by this English attempt to claim some of the credit: Le Verrier and Galle had known nothing of the work of Adams and of Challis. The French press took up the theme, accusing Airy, Herschel and Challis of "A Planetary Theft".[360]

In Britain, too, there was much public interest in the matter. Astronomers who could have searched for the planet themselves were aggrieved that they had been kept in the dark about Adams' work. John Hind of London's Regent's

358 The French astronomer, Lalande, had earlier wrongly recorded it as a star in 1795.

359 Whewell (ms.1846).

360 Standage (2000), p.119.

Park Observatory felt particularly badly treated, for he had corresponded with Challis about the search for the planet and Challis had never once mentioned Adams' work to him. With justice, he complained to Richard Sheepshanks of the Royal Astronomical Society of the "inexcusable secrecy", and that "The Cambridge people do the best for their own." In November, a crowded meeting of the Astronomical Society heard Airy and Challis give their own accounts of the circumstances; and Adams presented a factual description of his calculations, without any reference to the priority dispute.[361] The failure of Airy and Challis to make good use of Adams' work, and so discover the planet before the French was plain to see. The newspapers were forthright in their criticisms and the reputations of Airy and Challis plummeted. Adams was portrayed as the victim, unhelped and robbed of success, badly let down by his seniors. But J.D. Forbes of Edinburgh had no doubt that:

> It is established that in consequence of Leverrier's papers <u>alone</u> the planet was discovered in 1846. Everyone must see that there was not <u>a chance</u> of the Planet being found in England in 1846 from Adams's predictions, even fortified by the announcement of Leverrier's result at Greenwich on the 29th June. I say no chance for it seems evident to me (but you are a much fitter judge) that Challis's having recorded <u>one star less</u> in a sweep of the 12th August than he had done on the 30th July, the missing star not having been discovered to be so till (apparently) 6 weeks or 2 months after, was not only not a discovery, but <u>unless followed up at the time</u> could hardly have had the chance of leading to one. . . .
>
> . . . It was the confidence of his [Le Verrier's] predictions which staggered even the incredulous. It was his "express recommendation" to look for a disk which led Challis to it again on the 29th Sept. . . .[362]

Adams too must shoulder some of the blame. Unlike Le Verrier, he showed little enterprise and initiative in his dealings with the senior astronomers. He incompetently failed to present his results at the British Association by arriving on the wrong day. With the diffidence of youth, he had several times failed to communicate effectively with Airy; and, until he saw Le Verrier's papers, Airy had little reason to suppose that Adams' results should be taken seriously. Challis, however, could and should have helped Adams more. He was on the spot in Cambridge and knew of Adams' mathematical proficiency; and

---

361 Adams (1846–47); Standage (2000), pp.122–125.

362 Forbes (ms.1846).

he should have advised Adams to publish his work quickly, without waiting to refine his calculations. Also, he should have analysed his own observational data far more promptly than he did; and why did he not invite Adams to assist him in the task? It was only after Adams' paper appeared as a supplement to the *Nautical Almanac* that the quality of his work was finally appreciated.[363]

In a letter to Airy dated 18 November 1846, Adams attempted to justify his delay in replying to Airy's queries:

> I could not expect, however, that practical astronomers, who were already fully occupied with important labours, would feel as much confidence in the results of my investigation, as I myself did; and I therefore had our instruments put in order, with the express purpose, if no one else took up the subject, of undertaking the search for the planet myself, with the small means afforded by our observatory at St John's.[364]

This reveals another misjudgment. Rather than pressing the astronomers with the best equipment to search for the new planet, he contemplated using inadequate college facilities to look for it himself. Compounding his diffidence in approaching others "already fully occupied with important labours", he may misguidedly have wished to achieve both the prediction *and* the discovery all by himself. Adams' ability, and preference, to work entirely on his own were emphasised by a later Astronomer Royal, Harold Spencer Jones, in these words: "Adams had attacked this difficult problem entirely unaided and without guidance. Confident in his own mathematical ability he sought no help and he needed no help."[365]

In a letter to William Thomson, J.D. Forbes alluded to the different temperaments of the protagonists: "This it may be said was the result of French readiness and English bashfulness . . . but it is this confidence in results which has carried the Strongholds of Science. . . ." However, Forbes had valid reservations about the predictions of both; for,

> The residual errors from which A. and L. start are so different as to surprize us at the common result attained;—one is almost tempted to guess that there has been for once a happy throw of the dice in favour of discovery instead of <u>against</u> it (as usual), both in this, and in both L. and A. getting

[363] Adams (1851; 1896).

[364] Quoted in Jones (1947), p.21.

[365] Jones (1947), p.18.

> a correct Longitude with a grossly erroneous mean distance (36 instead of 30). . . . By all accounts Mr Adams must be as amiable as he is undoubtedly able and original, but I fear his friends are not judicious. The proceedings (lately) in the Astronomical Society, are I fear very injudicious & will undoubtedly be condemned by impartial persons at a later day. As to our worthy friend Challis, he comes out worst of all. I hope he will never try to find a planet again nor to write the history of one.[366]

Adams also seems to have had a strange, overly theoretical, attitude to the nature of scientific discovery. Writing to J.D. Forbes in 1855, he minimises the importance of the first observation of the planet as merely the "recognition" or "verification" of the discovery:

> . . . the first actual recognition of the planet by means of the telescope seem[s] to me to have a very indirect bearing on the merit due to either M. Le Verrier or myself. The verification of M. Le Verrier's prediction was equally a verification of my own. . . . My preliminary calculations [assuming circular motion] obtained in 1843 were much more satisfactory than you suppose . . . the longitude obtained differed only a few degrees (I think not more than ten) from the final result. . . .

Correcting Forbes' underestimate of his age, Adams wryly notes that "I was not so young in years at the time of making the discovery, as in knowledge of the world"; but he

> cannot plead guilty to the charge of want of enthusiasm in regard to the discovery. . . . With Professor Challis I had repeatedly discussed the subject, & he had promised to search for the planet when I had completed my calculations. Accordingly in the middle of September 1845, when the planet was near opposition & therefore most favorably situated for observation . . . I placed in Professor Challis's hands a paper containing not only the elements, but also the geocentric place of the planet, and I was much disappointed, on returning to Cambridge about a month later, to find that he had taken no steps to look out for it. . . .[367]

That is to say, Adams had hoped that Challis would look for the planet *nearly ten months* before Airy asked him to do so; and he had supplied him with a

---

[366] Forbes (ms.1847a).

[367] Adams (ms.1855).

good prediction of its position. Yet Adams had chosen to leave Cambridge for a crucial month, when he might have remained there to urge Challis on.

After much debate and dissent, the new planet was finally named Neptune. In 1846, the Royal Society awarded its Copley medal to Le Verrier, as they previously had to William Herschel for the discovery of Uranus. In the next year, by the lobbying of Herschel and Adam Sedgwick, the twenty-eight-year-old Adams was offered a knighthood. But Adams, though honoured by the offer, declined it on the grounds that he could not afford to keep up appearances on his limited income, and that it would be inappropriate for the recipient of a knighthood to work as a private teacher, as he had to. In 1847, Adams and Le Verrier finally met, and reportedly got on well together, at a meeting of the British Association for the Advancement of Science held in Oxford. J. D. Forbes wryly recorded the occasion:

> The Oxford meeting was very satisfactory and regards the meeting, Adams & Leverrier who were the great stars and who conducted themselves with great prudence and amity; to which perhaps the Circumstance that Leverrier speaks no English, and Adams no French, somewhat contributed. I had the singular good fortune to see Neptune for the first time in company with Leverrier, Adams, Struve & Challis.

In a letter sent to his wife Alicia a few days earlier, Forbes also mentions that he:

> . . . dined at Prof [Baden] Powell's where we had a small but excellent party including Airy, Lubbock, Adams, Leverrier & Struve . . . we heard that the evening was very fine & that Neptune might be seen. . . . Fancy the interest of seeing the New Planet for the first time in company with its <u>two</u> discoverers! . . . I did not get back to my College till very near two in the morning![368]

The above version of the controversy is based largely on the testimony of the main British protagonists, recorded after the event. Its veracity has recently been called into question by Kollerstrom (2006). Many key documents (including the so-called "Neptune file") had gone missing from the Royal Greenwich Observatory in the 1960s and were finally rediscovered in 1999 in the Institute of Astronomy at La Serena, Chile. Now in Cambridge University Library, the missing documents have been re-examined by Kollerstrom, along

[368] Forbes (mss.1847b,c).

with Adams' and Challis' own notebooks. His startling conclusion is that "their scrutiny *fails to endorse* the status traditionally assigned to John Couch Adams . . . as co-predictor of Neptune's position."

He correctly points out that all of Adams' conclusions reached before Le Verrier's prediction of Neptune's longitude in June 1846 were "private rather than public statements" and so did not have the status of a publication. Yet "A fairly small 'Cambridge network' soon came to control the narrative to an extraordinary degree, of how a new planet came to be co-discovered by two persons, more-or-less synchronously." Though Adams was certainly working on his predictions, he obtained several estimates that differed considerably from each other; and Kollerstrom doubts that he provided Challis with as accurate an estimate as was later claimed.

Adams' own diaries are missing for much of 1845–46, but a part for March 1846 has survived. They show him working closely with Challis at the Observatory: but Adams was concerned with the path of a new comet and with atmospheric refractions, not with the predicted comet. This is strange behaviour for one supposedly engrossed in the planetary search. Many other details of the "authorised version" are queried by Kollerstrom: though it seems that no one deliberately lied to bolster Adams' case, memories may have acted selectively in his favour.[369] One wonders, however, why Airy and Challis would have risked their own reputations as they did, had they not believed (though belatedly) that Adams was indeed the rightful co-predictor of the planet.

In 1848, Adams was awarded the Royal Society's Copley Medal, recognising him as Le Verrier's equal. In 1847, the Adams Prize at Cambridge was established by subscription, to mark his achievement.[370] Despite his fame, Adams had to relinquish his fellowship at St John's College in 1852, because he had not taken holy orders within the statutory ten years from appointment. But he was promptly elected to a fellowship at Pembroke College, where this rule did not apply, and where G.G. Stokes was also a fellow. Adams continued in Cambridge as a fellow and private tutor until 1858, when he was appointed as Regius Professor of Mathematics in St Andrews, Scotland. It was there that the photographic portrait shown in Figure 9 was taken by the pioneer

---

[369] See Kollestrom (2006). Quotations above are from pp.1–3.

[370] This prize is still awarded every two years for a substantial scholarly essay on an announced theme. At first, the chosen themes attracted few entrants. Accordingly, in 1855 James Challis consulted William Thomson about possible topics, and they selected "The Motions of Saturn's Rings" for the prize of 1857. The winner, and sole entrant, was James Clerk Maxwell: see Harman (1998), pp.48–57.

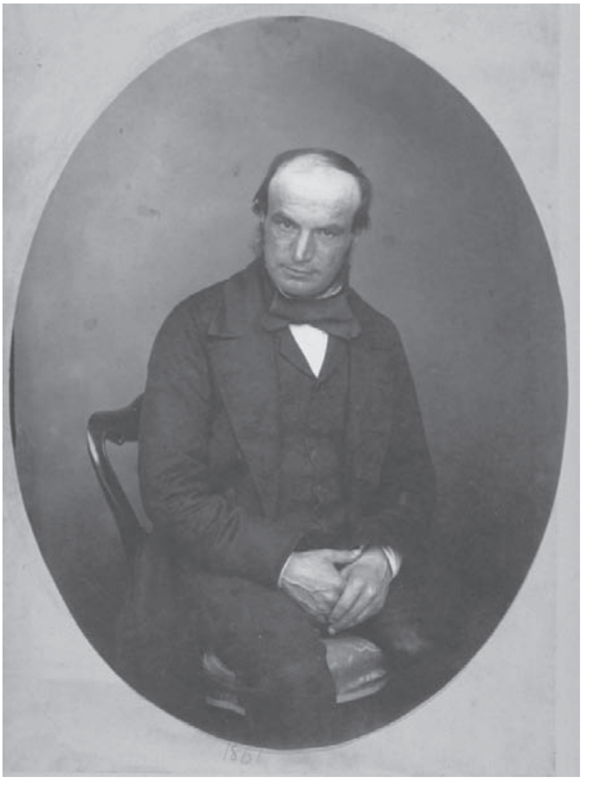


Figure 9. Photograph of J.C. Adams, by John Adamson of St Andrews 1859. (ALB8–55: courtesy of University of St Andrews Library Special Collections.)

photographer John Adamson. But he remained for just a single session, returning to Cambridge in 1859 to succeed George Peacock as Lowndean Professor of Astronomy and Geometry. Two years later, he was also appointed Director of the Cambridge Observatory in succession to Challis.

In taking up his Regius appointment at St Andrews—the *only* Crown-appointed Regius chair of mathematics in Britain—Adams was the last person to have to swear oaths of abjuration and allegiance, that were abolished by the 1858 Universities Scotland Act. In these, he swore fealty to Queen Victoria, abjuring the Jacobite succession, and he promised to act in accordance with the doctrines of the Church of Scotland.[371] Though these oaths were by then little more than out-dated formalities, they emphasise the importance attached

[371] Adams (ms.1858).

to established religion and the authority of the Crown. Originally drawn up to exclude Catholics and Jacobites, the oaths could still deter scrupulous applicants with strong religious or political convictions.

There was another dimension to Adams' appointment, that illustrates the extent of political patronage. In 1854, the Regius Professor Thomas Duncan fell ill, and it became apparent that the Tory Prime Minister Lord Palmerston intended to appoint one George Lees as Duncan's "Assistant and Successor", without consulting the University. Though Lees had some mathematical competence, being a lecturer at the Scottish Naval and Military College in Edinburgh, the St Andrews Principal David Brewster hoped for a better appointment. Brewster succeeded in persuading the authorities that appointing an "Assistant and Successor" was no longer legal, though it had often been done in the past. But the Government pressed on with the appointment of Lees as an "Assistant with all the powers and privileges of a Professor," a move that Brewster considered yet more illegal.

Writing to his influential friend Lord Brougham, Brewster maintained that Lees was "not qualified to teach the 3rd Mathematical Class so as to fit the Students for the Natural Philosophy Class taught by Mr Jackson who was 3^{d} Wrangler at Cambridge."[372] Lees was forbidden to teach, and he was deprived of his post when Brewster's legal action against the Government succeeded in 1858. This was a time of unstable Parliamentary coalitions, and by then the Palmerston administration had itself fallen. Accordingly, Brewster felt confident that "while Mr Walpole is in the Home Office, Mr Adams, the discoverer of Neptune, will certainly be appointed." So it proved; but, after all Brewster's trouble, Adams remained at St Andrews for less than a year.[373]

Arthur Cayley had hoped to gain the Lowndean chair in Cambridge; but, when Adams' appointment seemed certain, Cayley consulted him about the St Andrews chair. Adams truthfully replied that the teaching duties, though elementary, were much more onerous than at Cambridge; and Cayley did not pursue the matter.[374]

Back in Cambridge, Adams settled into the quiet and scholarly routine that suited him. Before becoming a professor, Adams had been a Moderator for the Tripos only once, in 1847, and he was never an examiner. It seems that he

---

372 Here, Brewster gives the wrong name of his professor. Thomas Jackson had died several years before; and it was Fischer who was fourth, not third, wrangler.

373 Brewster (mss.1854–58). "Mr Walpole" is Spencer Horatio Walpole, several times a Conservative cabinet minister.

374 Crilly (2006), p.233.

was unable to prevent the students from cheating, for a contemporary complained that: "Surely a man who discovers planets can find a practical way to conducting an examination fairly, and stop a low system of copying."[375] Like those of most other Cambridge professors, his lectures were not well attended; but he was one of the first Cambridge professors to allow women to attend.

Though he was not a particularly active participant in scientific societies, he twice served as President of the Royal Astronomical Society in 1851–53 and 1874–76, and he was President of the Cambridge Philosophical Society during 1861–63. He also served on a committee of the British Association for the Advancement of Science concerned with the observation and prediction of tides by harmonic analysis.[376] He was the first president of an Association for Promoting the Higher Education of Women in Cambridge, and he was involved in the establishment of Newnham College for women students in 1880. In 1881, George Airy retired as Astronomer Royal at Greenwich, and Adams was offered the post. But he declined because he felt that, at sixty-two, he was too old.[377]

Adams' later astronomical work could hardly be as spectacular as his prediction of Neptune, but he made other important contributions. These include studies of the Moon's apparently erratic motion during 1851–56, and of the Leonid meteor shower in 1867. The former work is an example of the "three-body problem" involving the mutual gravitational attraction of Sun, Earth and Moon. For this, in 1866 Adams was awarded the Gold Medal of the Royal Astronomical Society.[378]

Also of note are Adams' studies of the properties of the mathematical entities called "Bernoulli numbers", and the "Adams-Bashforth method" that accelerates the convergence of long numerical calculations at which he was so adept. His achievements in science were not of a grand innovatory sort: unlike Stokes, Thomson and Maxwell, he established no new fields of study. Rather, he restricted himself to well-trodden astronomical paths, but he did so with consummate technical expertise, carrying out long and tedious calculations with great exactitude. His collected scientific papers were edited by his younger brother, the physicist William Grylls Adams (Adams 1896).

---

375 Standage (2000), p.150.

376 Cartwright (1999), p.100. This committee was set up on the initiative of William Thomson.

377 In earlier times, Edmund Halley had accepted this post in 1720 when aged sixty-four, and held it for almost twenty-three years, until his death in 1742.

378 Hutchins (2004).

John Couch Adams' other interests were wide, encompassing history, geology, biology and politics; and his recreations included music, croquet, bowls and whist. He died, aged seventy-two, on 21 January 1892, within a few days of George Airy. In 1895, on the fiftieth anniversary of Adams' prediction of Neptune, a plaque was unveiled in Westminster Abbey in his honour. Significantly, Airy was never so honoured: despite his many significant contributions to science, his supposed negligence in the Neptune affair was not forgiven.

George Gabriel Stokes

George Gabriel Stokes was born on 13 August 1819 in the rural parish of Skreen, County Sligo, in the north-west of Ireland. His father Gabriel Stokes was the rector of the Episcopal Church of Ireland in the parish, and his mother Elizabeth Haughton was the daughter of another rector in Londonderry. In predominantly Roman Catholic Ireland, they were part of the immigrant ruling class of Anglo-Irish Episcopalians, socially isolated from, and resented by, much of the population. George was the youngest of eight children, born a full twenty years after his eldest brother John Whitley Stokes. Several older members of the Stokes family were prominent in academic, medical and religious circles.[379]

George Gabriel Stokes received his early education in the parish; then, from 1832, he attended a school in Dublin for three years, when he lived with an uncle. In 1834 his father died and the family had to leave the rectory; but from 1835 George was able to continue his education at Bristol College. There, the Irish-born headmaster was J.H. Jerrard, who had been a friend and contemporary of Stokes' elder brother at Cambridge; and the mathematics master was Francis Newman, an able mathematician.[380] Impressed by Stokes' mathematical prowess, Jerrard recommended that he apply to Trinity College, Cambridge, but Stokes instead entered Pembroke College in 1837.[381] In his second year, Stokes began private study with William Hopkins, and in 1841 he

---

[379] Fuller biographies of Stokes are in Larmor (1907), Wilson (1987; 1990), Wood (1995; 2003).

[380] He was the brother of John Henry Newman, the Anglican theologian who later became a Cardinal of the Roman Catholic Church.

[381] Though Stokes was almost exactly the same age as John Couch Adams, he was two years ahead of Adams at Cambridge. Adams did not become a student until around the age of twenty, whereas Stokes did so at eighteen. Stokes began his studies in the year that George Green graduated.

graduated as senior wrangler and first Smith's prizeman. He was promptly elected to a Fellowship of his college.

In 1849, Stokes might have joined William Thomson in Glasgow as Professor of Mathematics in succession to Thomson's father; but, despite Thomson's encouragement, he decided not to become a candidate, because of his strong Anglican objection to submitting to the test of conformity to the Presbyterian Church of Scotland. Stokes was elected to the Lucasian chair in Cambridge later that same year, in succession to Joshua King: he was the only candidate, and went on to hold this post for fifty-four years, until his death in 1903. So little-known was Stokes at the time of his appointment that *The Times* newspaper and two of three Cambridge papers incorrectly stated that his brother W.H. Stokes of Caius College had been appointed.[382]

Because the Lucasian chair was not well endowed, during 1854–60 Stokes held a second job as Professor of Physics at the Government School of Mines in London. Also, in 1854, both Stokes and J.J. Sylvester were unsuccessful applicants for a professorship at the Royal Military Academy in Woolwich. To Sylvester's disgust, the post went to Matthew O'Brien (3rd, 1838), another former pupil of Hopkins. O'Brien was already employed there as a part-time lecturer in astronomy, while also Professor of Natural Philosophy at King's College, London. O'Brien resigned his post at King's to take up that at Woolwich, but he died within a year, to be succeeded by Sylvester.[383] Would Stokes have resigned the Cambridge Lucasian Chair if he, rather than O'Brien, had been appointed? Presumably not, for there were precedents for absentee Lucasian professors. Charles Babbage held the post during 1828–39 but never lectured and rarely, if ever, visited Cambridge during his tenure; Babbage's predecessor, the deservedly forgotten Thomas Turton who held the chair during 1822–26, likewise never lectured; and Joshua King was unable to, having suffered a paralytic stroke.

In 1859, William Thomson again tried to persuade Stokes to move to Glasgow, writing to ask "Why have you not (if you have not) become a candidate for the Professorship of Astronomy . . .? I do not know why it did not occur to me sooner, but I have this morning had a letter from Arch Smith suggesting it." Though the salary was only £300 a year, this was substantially more than that of the Lucasian chair, and the job came with a house "very good & delightfully situated." Thomson emphasised that there were now no religious tests, as these had recently been abolished by Parliament. He also urged Stokes that it would be for the good of science to get him away from

382 Larmor (1907), v.1, pp.381, 382; Wilson (1990), v.1, letters 35–43, 53, 54.

383 Parshall (1998), pp.70–73.

Cambridge and London, "those great Juggernauts under which so much potential energy for original investigation is crushed." But Stokes was by now settled in Cambridge.[384]

Stokes had to resign his Pembroke fellowship in 1857 on marriage; but he was re-elected in 1862, when the rule banning married fellows was abolished. His wife, Mary Suzanna Robinson, was a daughter of Dr Thomas Romney Robinson, the astronomer of Armagh Observatory. They had five children, two of whom died in infancy. Elected a Fellow of the Royal Society of London in 1851, Stokes became the Society's Secretary in 1854; and he held this onerous post for more than thirty years until 1885, when he became the Society's President (1885–90). He was awarded two of the Society's medals: the Rumford medal (1852) and the Copley medal (1893). He was knighted in 1889 and, for a short time before his death in 1903, he was Master of Pembroke College.

During 1887–91, Stokes served as Member of Parliament for Cambridge University, when it and Oxford University first elected just one member each. He shares only with Isaac Newton the distinction of holding the three offices of Lucasian Professor, President of the Royal Society and Member of Parliament: and, like Newton, his oral contributions to Parliament were negligible. (It is said that he spoke only once, to request that a window be opened.)

Stokes was serious-minded to a fault, and very conscious that he lacked a sociable, outgoing personality. Feeling that his obsession with mathematical work might make him a less-than-ideal husband, he wrote several agonised letters to his fiancée. One, fifty-five pages in length, which (perhaps fortunately) has not survived, nearly persuaded Mary Robinson to break off their engagement; and the thirty-seven-year-old Stokes envisaged that he should "go to the grave a thinking machine unenlivened and uncheered and unwarmed by the happiness of domestic affection". Though there is little doubt that his home life was stable and contented, Stokes remained socially ill-at-ease, humourless and uncommunicative: several students invited to his home remarked on the embarrassingly long silences.

It has been suggested that Stokes' self-sacrificing and long-serving role as Secretary to the Royal Society during 1854–85 fulfilled a need to be part of the wider community, rather than remain the introverted scholar that suited his personality. In that public role, he certainly had a very beneficial influence on the Society's *Proceedings* and *Transactions*, by selecting suitable referees

---

384 Wilson (1990), v.1, letters 176, 177 (p.248). Arthur Cayley had also expressed interest in the Glasgow astronomy chair, but was considered unsuitable because of his lack of experience in observations and experiments: Crilly (2006), p.238.

Figure 10. Photograph of G.G. Stokes dated 1857. [From Larmor (1907), frontispiece, courtesy of Cambridge University Press.]

and by encouraging authors to improve their papers. But such unstinting administrative work diminished his own original research output, large though it was. Perhaps his personality also inhibited him from investigating more adventurously some of the most exciting and speculative scientific developments of his day. The physicist Lord Rayleigh (J.W. Strutt; 1st, 1865), who gave an address at Stokes' funeral, certainly thought so, describing him as sometimes "too cautious".[385] Whereas Stokes' friend William Thomson speculated (sometimes too wildly) about the age of the Earth and the fundamental composition of matter, and the younger James Clerk Maxwell proposed a new unified theory of electricity and magnetism, Stokes was never comfortable with speculative hypotheses: instead, he restricted himself for the most part to fluid mechanics and optics, and he did so to masterly effect.

385 Rayleigh (1903), p.xix.

Stokes published one hundred thirty-seven scientific papers under his own name, and just a single joint paper; and he also wrote several religious works. Remarkably, all Stokes' significant work on fluid mechanics was written during the two periods 1842–50 and 1880–98: in other words, when he was aged around 23–30 and 60–79. Between the ages of thirty and sixty, Stokes' published research concerned mainly optics, and mathematical problems deriving from optics.[386]

On Stokes' graduation, Hopkins recommended hydrodynamics as a fruitful field of research, but he could hardly have foreseen the extent of Stokes' contributions. Stokes had attended the hydrodynamical lectures of the Plumian Professor James Challis, but disagreed with Challis' erroneous views. In particular, he disputed Challis' claim that the governing equations were incomplete and had to be supplemented by a further equation. And he demolished, by providing counter-examples, Challis' misguided assertion that flows which possess no rotation (i.e. flows with zero vorticity) necessarily proceed along straight parallel lines. Their private disagreements soon became public with a sequence of papers in the *Philosophical Magazine* and elsewhere.[387]

At this time, too, Stokes was invited by William Thomson to contribute several "Notes on Hydrodynamics" to the *Cambridge Mathematical Journal*: these were a useful aid to students at a time when no adequate textbook existed. Outside Cambridge, Stokes first made an impact with his 1846 *Report on Recent Researches in Hydrodynamics* to the British Association for the Advancement of Science. But the major achievements of his early career were two great papers: one setting out, in definitive form, the equations of viscous fluid flow, and the other advancing the theory of water waves.[388]

Between 1822 and 1837, previous attempts at deriving the equations for viscous flow, and the analogous equations for distortion of elastic solids, had already been given in France by Navier, Poisson, Cauchy and Saint-Venant.[389] Stokes had not seen these before his own work was well advanced. Rather, he may have been influenced by some geological work of Hopkins that attempted to explain rock fissures: in this, Hopkins considered the forces acting on

---

[386] Stokes' collected scientific papers were published as Stokes (1880–1905). Some though not all of his voluminous correspondence is in Larmor (1907) and Wilson (1990). Wilson (1990) v.2, pp.763–765 also lists Stokes' scientific publications. Various aspects of Stokes' work are discussed by Wilson (1987), Paris (1996), Craik (2005).

[387] See Craik (2005).

[388] Stokes (1845; 1847).

[389] See Darrigol (2002; 2005).

either side of a notional plane surface within the rock.[390] Another likely influence is an optical paper by George Green, who formulated expressions for the tangential stresses associated with transverse waves propagating through a supposed light-transmitting "aether".[391] Though Stokes' final equations were essentially the same as those of the earlier French work, he had deduced them from more general and more physically realistic hypotheses.

These are the *Navier-Stokes equations*, which without the viscous terms reduce to Euler's equations. Stokes found several important new solutions. Among them is the motion induced by oscillating a flat plate in its own plane: this is confined to what is now called the "oscillatory Stokes layer". Later, he proposed an approximation for very slow viscous flows (now called "Stokes flows"). This allowed him, among other things, to predict correctly the rate of descent under gravity of small spheres falling through a viscous liquid (now called "Stokes' law for a sphere").

On water waves, Stokes learned from G.B. Airy's impressive survey article, "Tides and Waves" in the *Encyclopaedia Metropolitana*, which incorporated much of Airy's own original work; and also from two slightly earlier papers by George Green. He may also have seen two long, but flawed, papers by Philip Kelland. All three previous writers had been stimulated and tantalised by the new, and largely unexplained, experimental results of John Scott Russell. It was clear from Russell's results that the standard "linear" approximation, which is satisfactory for small-amplitude waves, did not apply to steeper waves.[392]

Supposing the liquid to be non-viscous, in 1847 Stokes developed a rigorous "weakly nonlinear" approximation which gave systematic corrections to the linear theory. He concentrated on periodic straight-crested waves propagating on the liquid surface under the action of gravity. In the linear approximation, these are just pure sine-waves, with a known speed of propagation that depends on the wavelength. But Stokes found that his finite-amplitude corrections cause the crests of gravity waves to be sharpened and the troughs flattened compared with a pure sine-wave; and, additionally, that there is a small increase in the wave speed. He also discovered that fluid particles do not move in closed oscillatory orbits (circles when the depth is unbounded), as predicted by linear theory. Rather, there is a small average

390 See C. Smith (1985, p.77; 1989).

391 Green (1838).

392 The work of Stokes and his predecessors on water waves is described at more length by Darrigol (2003) and Craik (2004; 2005); and his work on viscous flows by Darrigol (2002; 2005).

drift velocity in the direction of wave propagation, that is greatest at the surface and diminishes rapidly with depth. This "Stokes drift" is now known to have an important part in oceanic circulation and in transporting floating debris.

The features first predicted in this masterly 1847 paper were subsequently confirmed by experiments. Much later, Stokes went on to calculate yet higher-order corrections, using an improved method. His work provided a model of clear mathematical exposition that has since been applied in many other contexts, subject only to the limitations of weakly nonlinear theory.

Unfortunately, Stokes' theory failed to describe the "great wave of translation", or solitary wave, seen by John Scott Russell. Attempts previous to that of Stokes, by Green, Airy, Earnshaw and Kelland, had also proved unsatisfactory; and the unlucky Russell was attacked for alleged experimental errors. Only much later was Russell vindicated, when satisfactory solutions for the solitary wave were found by J. Boussinesq and Lord Rayleigh. These solutions cannot be reached by any weakly nonlinear approximation like that of Stokes.[393]

Though Stokes' revived interest in fluid motion during the 1880s was partly prompted by the need to prepare for publication his collected *Mathematical & Physical Papers*, this is only part of the story. Appointment to the Meteorological Council of Great Britain led him to consider practical aspects of wave propagation in open seas: how best to measure wave amplitudes and periods from ships, and how such information might be used to deduce weather conditions at a distance. As practical illustrations, he examined ships' logs, and showed how to deduce the location of distant storms from the measured waves. His regular family holidays on the north coast of Ireland played some part also. The family normally stayed in accommodation attached to Armagh Observatory, where Stokes' father-in-law was Astronomer. Stokes' daughter, Mrs Laurence Humphry, recalled these visits:

---

[393] See Bullough (1988), Darrigol (2003; 2005), Craik (2005). In recent times, the solitary wave has been recognised as an integral part of a sophisticated *soliton theory*—also called the "theory of inverse scattering"—which permits solution of numerous important partial differential equations previously resistant to attack. From these mathematical discoveries have come stunning advances in optics and laser technology, which have revolutionised tele-communications.

Russell gave up pure science to become a well-known naval architect and engineer. He was involved with building London's Great Exhibition of 1851, and he collaborated with Isambard Kingdom Brunel on the huge *Great Eastern* steamship: see Emmerson (1977).

> Later, in the Long Vacations we always went over to stay at the Observatory of Armagh, and afterwards went with the Armagh party to some seaside place, oftenest the magnificent neighbourhood of the Giant's Causeway. . . .
>
> There was a cave called the Land Cave which we always visited after storms had been ploughing up the Atlantic. It had a sort of window opening into it from the land, so that we could see the great waves come in. . . . He made a good many wave-observations there, not about steep sea-waves, for that was much earlier, but I think he was trying to find out the relation of the waves to one another and why the ninth wave was so much larger than the others. He told me that he was nearly carried away by one of these great waves when bathing as a boy off the coast of Sligo, and this first attracted his attention to waves.[394]

It was in a letter to Dr Robinson on 6 January 1876 that Stokes first described the phenomenon of "group velocity", whereby a finite "packet" of waves travels at a speed different from that of individual wave crests. Stokes soon realised that this was a previously unnoticed consequence of the standard theory of wave motion. The corresponding mathematical theory made its first appearance later that year, as a Smith's Prize Examination question set by Stokes.[395]

Late in his career, Stokes studied the form of the highest possible periodic wave in deep water. By a beautifully simple argument, he showed theoretically that such a wave must have a sharp crest with slopes meeting at a corner of 120 degrees, rather than the 90 degrees claimed by J.W. McQuorn Rankine of Glasgow. But, not content with theory, he wrote of

> taking off my shoes and stockings, tucking up my trousers . . . and wading out into the sea to get in a line with the crests of some small waves . . . it did seem to me that the waves began to break while their sides still made only a blunt angle, a good deal less than 90°. I feel pretty well satisfied that the limiting form is one presenting an edge of 120°.[396]

Though Stokes himself did little work on fluid mechanics between 1843 and 1880, almost all the leading British practitioners had studied at Cam-

394 Larmor (1907), v.1, p.31.

395 Larmor (1907), v.1, p.337; Stokes (1880–1905), v.5, p.362.

396 Wilson (1990), v.2, pp.498, 499.

bridge and had attended his lectures. He, more than anyone, was responsible for establishing Britain's pre-eminence in this field.

Stokes' contributions to optics and "aether theory" are summarised in Chapter 12, as they are best considered together with the work of others: accordingly, they need not be repeated at length here. His interest in fluorescence dates from the 1850s, when he experimented with quinine, which glows when irradiated by "dark light" with wavelengths beyond the visible range.[397] He rightly concluded that the irradiation caused the atoms of quinine to vibrate at a definite frequency in the visible range. Later, he interacted fruitfully with the skilled experimenter William Crookes (1832–1919) on cathode rays in the 1870s and X-rays in the 1890s.[398]

A non-technical account of just one of Stokes' major mathematical discoveries seems appropriate. Perhaps the most famous is that now called the *Stokes phenomenon* in the theory of asymptotics. Stokes analysed the intensity of light in the neighbourhood of a "caustic", of which the rainbow provides a good example. Light of each colour emerging from a spherical water droplet, after two refractions and one internal reflection, is not just a simple ray, as supposed in the elementary explanation of a rainbow. Instead, it forms a *caustic*: a locally bright place near where many rays converge then diverge again. Because these rays consist of waves, their combination produces an interference pattern of bright and dark bands where they alternately reinforce and cancel one another. Each colour behaves slightly differently, and their combined effect gives "supernumerary rainbows", as they are called, which can appear as separate rainbows within the main one, or modify the colours of the main arc. (These are quite distinct from the secondary rainbow often seen outside the main arc: this is caused by double internal reflections.)

A previous study by Airy had shown that the intensity of light of a *single* colour, in the vicinity of a caustic, could be expressed as a certain integral expression, now known as the "Airy function".[399] Its value depends on a parameter m that measures angular distance across the caustic. Dark bands

397 He also administered the same quinine to members of his family when they fell ill.

398 Many of Crookes' experiments stemmed from his wish to understand the behaviour of his "radiometer" of 1875: its vanes, silvered on one side and blackened on the other, rotate when exposed to direct sunlight. Now mass-produced for sale in gift and toy shops, Crookes' radiometer demonstrates the kinetic theory of gases in action. And the cathode rays that he first studied are universally present in neon lights and, until recently, television receivers. Crookes was also interested in psychical research, on which he published papers in *The Quarterly Journal of Science*, of which he was editor.

399 Airy's integral is $F(m) \equiv \int_0^\infty \cos\frac{\pi}{2}(x^3 - mx)dx.$

of the resulting interference pattern correspond to values of m at which the Airy function equals zero. But finding these values was hard, and Airy could calculate only the first few of them (though nowadays it is a fairly straightforward computer-aided task).

Stokes adopted a novel approach, seeking an approximation when m took very large values, both positive and negative. This is called an *asymptotic approximation*. His answer was made up of a sum of two known functions, each multiplied by constants, A and B say. When m was large and positive (i.e. where the interference patterns occur), Stokes was able to evaluate these constants, and so tabulate no fewer than fifty zeros of the integral. Where m was large and negative (where no interference pattern occurs) the two functions have a different, non-oscillatory form, but they still correspond mathematically to those found when m is positive. But Stokes was surprised to discover that the constants A and B were not the same as before: in fact, one of them had to be zero to prevent the intensity of light becoming infinite as m approached minus infinity.

Lesser mortals would have been content to leave it at that, as the original problem was solved, but Stokes wished to understand *why* the constants changed in this unexpected way. To do so, he extended the definition of the Airy function to embrace complex, rather than just real, values of m. That is, he supposed that m has real and imaginary parts, m_r, m_i, where $m = m_r + im_i$ and i is the square root of –1. He found that, in the plane represented by all pairs of numbers (m_r, m_i), there are three straight lines, across which the constants A and B abruptly change: these are now called the *Stokes rays*.

Stokes had discovered a characteristic feature of asymptotic representations of *many* functions, not just the Airy function, and this now has a central place in the theory of asymptotic expansions.[400]

Now we turn to Stokes' religious role as an active and devout Anglican, eager to reconcile science and religious belief.

In 1886, Stokes was elected President of the Victoria Institute, which also called itself the "Philosophical Society of Great Britain". This body was formed in 1865 by a group of Christians concerned by perceived attacks made in the name of science. Another of its supporters was the lawyer Henry Cadman Jones (2nd, 1841), who had come second to Stokes in the Tripos list. Though

---

[400] In recent years, renewed study of these Stokes rays has led to an extended theory of *exponential asymptotics*, in which the paradoxical discontinuity of the constants is removed. Instead, it was discovered that the values of the constants change continuously but very rapidly, across exceedingly thin layers. Once again it was physicists who accomplished this mathematical advance, most notably Michael Berry in 1989, following pioneering work by R.B. Dingle in 1973.

Cadman Jones was described in his *Times* obituary as "too shy and reserved to win a foremost place in the [legal] profession", he was active in Church affairs as a trustee of the Religious Tracts Society.

The Victoria Institute's first object was:

> To investigate fully and impartially the most important questions of Philosophy and Science, but more especially those that bear upon the great truths revealed by Holy Scripture, with the view of defending these truths against the oppositions of Science, falsely so called.[401]

At the outset, this journal was, in today's terms, "hardline fundamentalist" in character. In its first volume, it republished a pamphlet by the Secretary of the Society, J. Reddie, entitled *Scientia Scientiarum*.[402]

Reddie makes clear that the Institute was founded to counter the "supposed contradiction between science and the Scriptures . . . put forward in the 'Essays and Reviews,' as ground for rejecting the theory that the Scriptures are wholly inspired; and Dr Colenso and others [who] have followed the same path. . . ."[403] Throughout, Reddie's thesis is that *no* scientific findings that contradict clear and unambiguous Biblical statements can be true science, and will eventually be shown to be false. New and radical interpretations of the Bible, like those of *Essays and Reviews*, and claims by Bishop Colenso that parts of the Bible cannot be factually accurate, had to be resisted by disputing the scientific evidence.

Reddie goes on to criticise recent geological evidence for the extreme age of the Earth, its supposed internal molten state, the creation and composition of granite, and speculations on the Earth's "nebular" origin, condensed from diffuse gaseous matter. He also points out the conflict between rival scientific models of the Universe: according to Newton, heavenly bodies move through an empty void; whereas, according to Aristotle and Descartes, space is filled by a "plenum" of aether. Though no longer central to dynamics, the aether

---

401 *Victoria Institute J.* v.1 (1866). The journal's full title is *Journal of the Transactions of the Victoria Institute or Philosophical Society of Great Britain* and it was published annually from 1866.

402 This, and similarly doctrinaire early articles, are now readily available on, and commended by, the Internet website of a "Creationist" organisation. Many have also been collected in Lynch (2002).

403 The collection *Essays and Reviews* (Temple *et al.* 1860) was discussed in Chapter 7 (under heading "The Anglican Church at Home and Abroad"); Colenso's work is treated below in Chapter 10 (under heading "The African Bishops: J.W. Colenso, C.F. Mackenzie and H. Cotterill").

had recently been invoked to explain a supposed small resistance to planetary motion, and it remained the basis for theories of the propagation of light. While such major uncertainties existed within science, it seemed perverse to abandon belief in literal interpretations of the Bible.

Presumably, Reddie's pamphlet was first written before the publication in 1859 of Charles Darwin's *The Origin of Species*, for he does not mention it. But an article by George Warington "On the Credibility of Darwinism" appeared a year after the reissue of Reddie's work. Warington's cogently written article is very supportive of Darwin's theory, but he sidesteps the theological implications by saying that:

> Its relations to Scripture I purposely pass by for I do not believe that Scripture was ever meant to teach us science, and hence the less that they are brought into comparison, the better for each. . . . [But] I confess myself utterly at a loss to understand how any objection can possibly be taken to Darwinism theologically.[404]

The Chairman thanked Warington for his clear and systematic exposition, deferring discussion to a future meeting; but he could not resist declaring his opinion "as an anti-Darwinian . . . that Darwinism is not a bit more credible than I thought it was before." Reddie, as Secretary, added that he too had "not been in the least convinced by anything that Mr. Warington has advanced. On the contrary . . . I feel . . . only the more persuaded that the theory of Mr. Darwin is inharmonious, inadequate, inconsistent, and utterly incredible." Because this statement brought cries of "Hear, hear" from the audience, one must feel sympathy for the poor speaker and admire his courage in addressing such a hostile gathering.[405]

One might think that George Stokes, a leading British scientist, would never have agreed to take on the presidency of an organisation so antipathetic towards science. But this is to underestimate the central importance of religion in Stokes' life. He would surely have agreed wholeheartedly with the stated aim of the Institute to "investigate fully and impartially the most important questions of Philosophy and Science, but more especially those that bear upon the great truths revealed by Holy Scripture . . ."; and he cared deeply that science and religious belief should be harmonised.[406]

---

404 Darwin (1859); Warington (1867), sect. 4.

405 Warington (1867), addition at end.

406 In his comparative study of *Kelvin and Stokes*, David B. Wilson devotes an interesting chapter to "Religion and Science" where such matters are considered in greater detail. Wilson also notes that Stokes was for a time vice-president of the Christian Evidence Society: Wilson (1987); Wilson (1990), letter 541.

Stokes held the Presidency of the Victoria Institute from 1886 until his death seventeen years later. His acceptance of this post, and his election as Member of Parliament for Cambridge University during 1887–91, were not without controversy. He accepted these positions while President of the Royal Society; and T.H. Huxley, its previous President, complained in a letter to *Nature* that the Royal Society's President should remain apart from politics and conservative religion. (In fact, the biologist and agnostic Huxley had objected to Stokes becoming the Royal Society's President on two previous occasions, in 1878 and 1883.) But William Thomson wrote supportively to Stokes that "We are *very much* displeased with that article in *Nature*. I think on the contrary, your agreeing to be member [of Parliament] was most patriotic and public-spirited. Personally, and for the sake of science I can't help feeling sorry that it will take up so much of your time."[407]

Several eminent scientists addressed the Victoria Institute during Stokes' Presidency; and among its Corresponding Members were William Thomson, the geologist James Geikie, the chemist Louis Pasteur, and the African explorer H.M. Stanley.

Formative influences on Stokes' religious beliefs were his early upbringing in a devout Anglican Evangelical home, and his study at Cambridge of the writings of William Paley. But Stokes' instinctive horror of eternal damnation led him, in the 1830s, to espouse the growing alternative view of "conditional immortality", whereby the "saved" became immortal after death, but the rest were consigned to oblivion rather than to eternal torment. He also supported the controversial opinion of Bishop Colenso that native African polygamists need not renounce their extra wives in order to be baptised into the Church. These theological concerns led him to publish in 1897 his book *Conditional Immortality: A Help to Sceptics*.[408]

Stokes' other religious writings include several magazine articles and his two-volume Gifford Lectures on *Natural Theology*. In the latter, he describes his own theory of man's tripartite nature, consisting of body, soul (which he seems to equate with thought), and spirit or ego which survives death: but D.B. Wilson pertinently asks whether Stokes had "needlessly conflated soul and thought, thus artificially creating the requirement of a third entity?"[409]

T.H. Huxley was an early supporter of Darwinism, which he incorporated into his own materialistic world view. So too was the physicist and materialist John Tyndall, who in 1874 outlined to the British Association a theory even

---

407 Wilson (1987), p.16 n36.

408 Stokes (1897): see also Chapter 10 (under heading "The African Bishops: J.W. Colenso, C.F. Mackenzie and H. Cotterill"); Wilson (1987), pp.94, 95 n3.

409 Stokes (1891; 1893); Wilson (1987), p.83.

more radical than Darwin's. Tyndall argued that the principle of conservation of energy—so expertly exploited by William Thomson in his researches—did not distinguish between living and inanimate matter, and so the distinction between life and non-life was a false one that might as well be eradicated. Both Stokes and Thomson strongly disagreed with Tyndall's materialism. Stokes replied that human beings were indeed subject to the same law of conservation of energy as were inanimate objects; but, likening a human being to a moving train, he compared the human will to "the intelligence of the engine driver", rather than to "the coals under the boiler" which provides the energy. At Stokes' invitation, Thomson (or rather Lord Kelvin as he had become) addressed the Victoria Institute in 1897, when he spoke "On the Age of the Earth as an Abode Fitted for Life".[410] And Henry Cotterill, by then Bishop of Edinburgh, twice addressed the Victoria Institute on science and religion.[411]

Another who took issue with Tyndall's materialism was P.G. Tait, who also believed that the science of energy was entirely in harmony with Christian belief. Together with an Edinburgh colleague, Balfour Stewart, he published anonymous works, *Unseen Universe, or Physical Speculation on a Future State* (1875) and *Paradoxical Philosophy* (1878). They claimed, somewhat controversially, that, though the visible Universe was decaying because of dissipation of energy, there remained an unseen eternal whole that was self-renewing, and throughout which the dissipation of mechanical energy was not a fundamental law.

Stokes, like most scientists of the time, was persuaded by Laplace's nebular hypothesis for the origin of the solar system. He tried to reconcile this with the Genesis story in an article entitled "Genesis and Science" (Stokes 1891b), by arguing that the "days" during the creation did not correspond to 24 hours, there being as yet no Sun or Earth. Only on the "fourth day" would the Sun have become visible from Earth. But he finally had to admit that "if we suppose that the record in Genesis was meant for the people of the time, . . . then it would be preposterous to demand scientific accuracy of detail." But even this was further than many members of the Victoria Institute were willing to go.

As to Darwin's Theory of Natural Selection, Stokes was sceptical, as also were Hopkins and Thomson. Stokes accepted the fact of variation within

[410] Wilson (1987), p.91; (1990), letters 590, 596; Thomson (1899).

[411] "On the True Relation Between Scientific Thought and Religious Belief" (1878), and "The Relation Between Science and Religion, Through the Principles of Unity, Order, and Causation" (1880).

species, both by natural evolution and adaptation in Nature, and by selective breeding of domesticated animals. He supported study of the evidence of links between species, but he was not willing to accept that evolution was necessarily a continuous process. Rather, he warned that, in studying "second causes" one must not forget the divine First Cause, nor ignore "the wonderful proofs of design which . . . meet us at every turn." Stokes was certainly swayed by the underestimate by William Thomson of the age of the Earth, which was far too short to permit gradual evolution of all species by natural selection from a common source. There was still room for rational doubt over the compatibility of the Darwinian law of "survival of the fittest" (a phrase coined not by Darwin, but by the philosopher Herbert Spencer), the geological evidence of fossils, and known physical laws.[412]

In short, George Gabriel Stokes was one of the most influential and original physical scientists of his time, as active in public scientific affairs as in his own researches. He was an excellent lecturer, who for more than fifty years imparted his enthusiasms to generations of Cambridge undergraduates. He achieved fundamental advances in fluid mechanics, optics and geodesy. And, as a committed Anglican well known in Church circles, he made untiring efforts to reconcile science with religious belief.

Harvey Goodwin

Harvey Goodwin was born on 9 October 1818 at King's Lynn in Norfolk, the second of five children who survived beyond infancy. His father practised as a solicitor in the town. Throughout his school years, Harvey Goodwin had to bear adverse comparisons with an elder brother, Charles Wycliffe Goodwin, who had a prodigious talent for languages and "none of the ordinary tastes that lead small boys into boundless mischief."[413]

Harvey Goodwin long suffered from undiagnosed short-sightedness; but, once this was rectified by spectacles, he soon found that he could outdo his brother in mathematics. In preparation for Cambridge, his father arranged for private lessons, making an inspired choice of tutors. In the summer of 1835, Harvey studied at Keswick, in the Lake District, with William Hepworth Thompson, then a Fellow and later the Master of Trinity College,

---

[412] Stokes (1869); Wilson (1987), p.10.

[413] Rawnsley (1896), p.5. Charles went on to become a noted Egyptologist and one of the authors of *Essays & Reviews*. Rawnsley's biography is the prime source of information on Harvey Goodwin's life.

Cambridge.[414] At Keswick, Goodwin also met the mathematician John Henry Pratt, Fellow of Gonville & Caius College and future Archdeacon of Calcutta, who was similarly engaged in tutoring. Then, from October 1835, he studied for a year with the Rev. James Challis, rector at Papworth St Everard, near Cambridge. When Challis was elected Plumian Professor of Astronomy and Experimental Philosophy at Cambridge, Harvey Goodwin's classes continued at the Observatory.

By the time that Goodwin enrolled at Caius College in October 1836, he was already equipped with a good knowledge of the first-year topics in classics and mathematics. Disappointed that he came only fifth in the College examinations in classics, he decided to concentrate his efforts on mathematics, for which he had won first place. Consequently, during the long vacation of 1837, he studied privately with J.H. Pratt in Wales; and, from the start of his second year, he enrolled with William Hopkins. In 1840, Goodwin was second wrangler, behind Robert Leslie Ellis, of whom he later wrote an appreciative biographical memoir.[415]

In 1838, Hopkins chose Boulogne as the destination of the summer reading party for his students, but the young Harvey Goodwin was not impressed by his first trip overseas. He wrote to a sister that:

> a very nasty place it is . . . I am not aware of a single feature which recommends it . . . the place is dirty and, until the nose gets hardened to it, the smells you encounter about the town are by no means of a pleasant character. . . . The English residents are anything but select, forasmuch as it affords a convenient asylum for English gentlemen whose creditors are rather pressing for money.

He thought the French "an amazingly lazy set of fellows" and considered French cooking "vile". Despite this experience, four years later Goodwin agreed to a second overseas trip, again arranged by Hopkins. This was a serious scientific excursion to Switzerland to study glaciers, where they stayed with Louis Aggasiz on the Aar glacier, and visited the Mer de Glace with J.D. Forbes as their guide. Later in life, he was to spend several happy holidays on the Continent.[416]

---

[414] Thompson had himself been tutored by George Peacock, but he was a better classicist than mathematician, becoming Regius Professor of Greek in 1853.

[415] In Walton (1863).

[416] Rawnsley (1896), pp.43, 57.

Goodwin's one serious rival in the Mathematical Tripos was the gifted R.L. Ellis. But Ellis suffered from poor health and it was doubted that he would be able to complete the rigorous examinations without a breakdown. Characteristically, Goodwin wished that Ellis should do himself justice, for he would take no satisfaction "to find oneself decorated with a false halo of glory in consequence of the physical weakness of an incomparably superior man."[417] Ellis's stamina held out during the examinations: he became senior wrangler ahead of Goodwin and he won the first Smith's Prize. Goodwin was second wrangler, and he gained the second Smith's Prize after taking a fifth paper to separate him from the third wrangler, Woolley.

Because no fellowship was immediately available at Caius, Goodwin was appointed to the college's Sadlerian Mathematical Lectureship, took private pupils and studied for the priesthood. He gained his fellowship a year later; and he was an examiner, and R.L. Ellis a moderator, for the 1844 Mathematical Tripos. In the following year, the two exchanged roles, and Goodwin continued as an examiner for the further year of 1846. He and Ellis became good friends, and Goodwin was doubtless influenced by Ellis' wide intellectual interests. In 1844, while studying for the priesthood, Goodwin helped with the pastoral work of a Cambridge parish, and he preached his first sermons. In the next year, he contributed mathematical papers to the *Proceedings of the Cambridge Philosophical Society* and the *Cambridge Mathematical Journal*.

In 1845, just five years after he had himself taken the Mathematical Tripos, he had the self-confidence to issue a thirty-five-page pamphlet criticising the arrangements. He urged restoration, in a modern English form instead of Latin, of the *viva voce* "Exercises" or disputations, that had been dropped contrary to regulations. This, he felt, would differentiate between students who understood basic mathematical principles, and those who had merely learned to perform algebraic manipulations without true understanding. He also urged the separation of the Classical and Mathematical Triposes, which at present injured each other. On the one hand, "some of the best scholars of the year are prevented from competing for Classical Honours by previously failing to obtain Mathematical". On the other, "The standard of Mathematical honour at present is, I hesitate not to say, absurdly low . . . the present union of the Mathematical with the Classical Tripos is . . . an effectual bar against improvement."[418]

---

[417] Rawnsley (1896), p.45.

[418] Goodwin (1845), quotations from pp.24, 26.

In 1842, Goodwin had become engaged to be married to Ellen King, a niece of Joshua King, the President of Queens' College and, during 1839–49, the Lucasian Professor of Mathematics. On 13 August 1845, the two were married, after Goodwin had secured a curacy at St Giles, Cambridge, which brought greater financial security. Goodwin was an able flautist; and, at their home, the couple frequently welcomed friends and undergraduates for tea and music-making, when Goodwin not only played his flute but "sang Scotch songs with vigour and feeling."[419]

Goodwin continued as a private mathematical tutor, mainly of students destined for the Classical Tripos who were not aiming for high mathematical honours. He schooled them effectively in the more elementary topics which would secure them a respectable place as a Junior or Senior Optime. For this purpose, in 1846–47 he published a successful *Elementary Course of Mathematics*, which covered the material of the first three days of the Tripos examinations, and an accompanying *Collection of Problems and Examples*. Though criticised by some as a "cram book", it was reissued in several editions, and its success was later praised by N.M. Ferrers. (Ferrers, who had studied under both Goodwin and Hopkins, was senior wrangler in 1851 and later became Master of Caius College.) Among Goodwin's critics was William Whewell, and Goodwin was sufficiently incensed to publish a pamphlet in reply.[420]

More textbooks followed: a two-part *Elementary Mechanics: Designed Chiefly for the Use of Schools* covered statics and dynamics; and astronomy was served by Goodwin's translations of the first five chapters of Jean-Baptiste Biot's *Traité Élémentaire d'Astronomie Physique*. Much later, in 1867, an *Elementary Analytical Geometry* appeared under the joint names of Goodwin and the Rev. Thomas Grenfell Vyvyan.[421]

In 1848, on the recommendation of Joshua King, Goodwin was appointed vicar of St Edward's, in Cambridge, where he preached to large congregations of parishioners and undergraduates. Though not at first a gifted preacher, he soon developed an effective and straightforward style, and a brevity that was much appreciated. In 1853, he was offered the South African Bishopric of Grahamstown, knowing that his friend C.F. Mackenzie would volunteer to accompany him if he accepted. Under pressure to remain in his Cambridge post, he followed the advice of W.B. Hopkins and others to decline the offer. Soon after, Mackenzie accompanied Colenso to Natal, but not before he had led a successful clandestine campaign to increase Goodwin's salary at St Edward's to the

419 Rawnsley (1896), p.64.

420 Goodwin (1846; 1847; 1851); Ferrers (1892); see also Rawnsley (1896), p.66.

421 Goodwin (1851–53); Biot (1850); Goodwin & Vyvyan (1867).

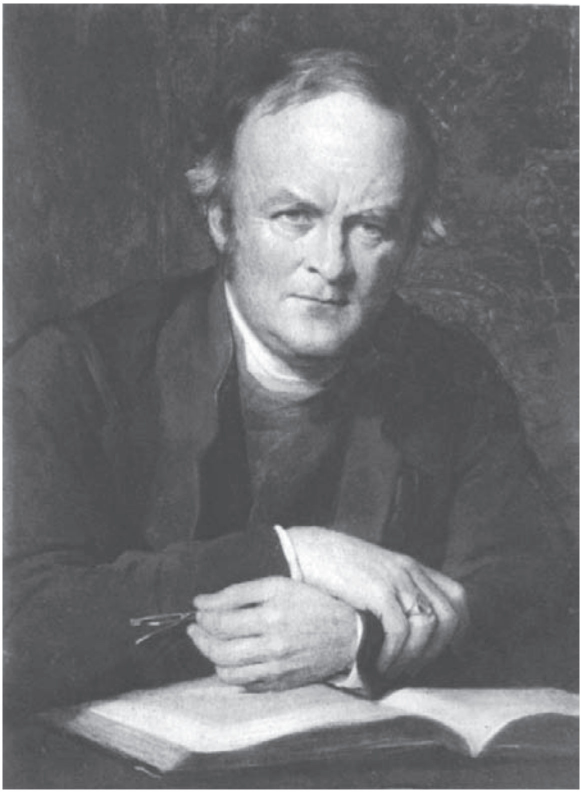


Figure 11. Bishop Harvey Goodwin, from a portrait by George Richmond R.A. [From Rawnsley (1896), frontispiece.]

level of £300 per annum offered by another parish. Goodwin was also an active supporter and secretary of the "Industrial School" opened in 1850, to assist poor boys of the city.

In 1858, Goodwin was offered, and accepted, the post of Dean of Ely.[422] In this post, Goodwin succeeded that other able mathematician, George Peacock, who had just died. Soon afterwards, he was awarded the degree of D.D. by the

[422] Unusually, the letter of invitation informed him that the position had already been refused by both Henry Philpott, then Master of St Catharine's (senior wrangler in 1829 and a Hopkins pupil), and William Selwyn (6th, 1828), the extremely well-paid Lady Margaret Professor of Divinity: Rawnsley (1896), p.84. William Selwyn also refused the bishopric of New Zealand, which was taken up to good effect by his brother, George.

University; and, with his wife and now seven children, he moved the short distance from Cambridge to the great mediaeval cathedral of Ely.

At Ely, he enthusiastically continued the restoration work begun by Peacock on the fabric of the cathedral and its surrounding buildings. He also encouraged the improvement of Church music and supported the performance of works by living composers; he sponsored a new dispensary building for the poor and sick; and he pressurised the Local Board of Health to improve the notoriously bad roads of the city. Within his diocese, he supported the formation of literary clubs and scientific societies; and he founded a Working Men's College which, however, did not long survive. His direct involvement with the restoration of the cathedral won the respect of the workmen: he could discuss knowledgeably with them the mechanics of handling large beams, and himself accompanied his clerk of works to distant wood sales to find suitably large timbers. Though genial and friendly to all in public, he could be brusque and forceful on committees. His uncompromising style led to occasional difficulties: he was eventually unseated as chairman of the Ely Board of Health after his snub of an influential official who "was leading an immoral life."[423]

Despite the pulling of many factions that were threatening to split the Anglican Church, Goodwin allied himself with none, but advocated the integration of religion with everyday life and work. At national level, he was a regular participant in the Anglican Convocation, where he became conversant with current debates and served on various committees, including that on the Colenso affair. Appointment to several Royal Commissions followed, including a seemingly interminable one on ritual. On these, his lack of factional affiliations earned him a reputation for "clear good sense and reasonableness."[424] From 1863, travel to France, Switzerland and Italy deepened his love of fine architecture.

In 1869, the Prime Minister W.E. Gladstone wrote to Goodwin to invite him to become the next Bishop of Carlisle; and his election was duly confirmed and consecrated at York Minster on 29th and 30th November. Though he encountered initial hostility from some of his rural (and poorly educated) clergy towards a southerner imposed on their northerly diocese, he soon built up a reputation as a bishop of the people as well as of the clergy. He took part in discussions of educational reform, and he strove to unify the work of the Church throughout his diocese.

Once installed in his splendid Carlisle seat of Rose Castle, he declared that its portcullis should never be closed. He also leased a London residence at 118

423 Rawnsley (1896), p.115.

424 Rawnsley (1896), p.118.

Harley Street, where he lived for three months of each year in order to play his part in national affairs. He regularly attended the House of Lords, supported charitable and missionary societies (including the Universities' Mission to Central Africa), and attended councils of the Ecclesiastical Commission. The question of disestablishment of the Church was in the air, but Goodwin saw no advantage in separating Church and State.

In 1877, a plan was devised to pipe Cumberland water to the rapidly growing city of Manchester. Goodwin—a proto-environmentalist—objected not to the principle of taking water, but to the means of doing so by building a dam that would destroy the natural scenery, the necessity not having been demonstrated. In the following year, he suffered a sad loss from which he never completely recovered: the death from scarlet fever of his second son, George Gonville Goodwin. Not long before, George had been appointed by his father as curate, and then rector, of the nearby parish of Crosthwaite.

Though no longer a practitioner, Goodwin retained a keen interest in science and mathematics. In 1881, he contributed an article on William Whewell to *Macmillan's Magazine*; this reflects thoughtfully and critically on the latter's accomplishments:

> Whewell was not really great as a mathematician. There are indications in his writings of a certain rude strength, but he had not the true mathematical instinct. He had no taste for the more refined methods of mathematical analysis, and, so far as I know, he made no real mathematical advance, neither was he great as a lecturer, or as a writer of books for the University. He had not the gift of imparting knowledge easily and agreeably; and I may add he was not great as an examiner.

But, after demolishing Whewell's reputation in virtually every normal academic activity, he goes on:

> Nevertheless, every one felt in those days that Whewell was our great Cambridge man. As Master of Trinity he was the prominent feature of the University till the day of his death. He handed on the lamp; and though his books may become antiquated, the direction given to the scientific and philosophical thought by Whewell's writings may have an influence upon men's minds deep and permanent, and not to be adequately measured by the size of his printed works.[425]

[425] Quoted by Rawnsley (1896), pp.214–215.

Goodwin was always keen to reconcile science and religion. In an Oxford sermon, he assured undergraduates that:

> I would not . . . depreciate knowledge. I have been brought up in a school where such depreciation is impossible; I have followed Newton in his wonderful discoveries, and have gone some way with those who, with an improved calculus and with great genius, have carried the mighty discoverer's work far beyond the limits which he himself reached. I look with intense interest . . . upon any step which is taken in the path of true science, and believe that in following that path men are only following the will of God.[426]

Holding such sentiments, he was a natural choice to preach the funeral sermon on Charles Darwin in Westminster Abbey on 1 May 1882. After paying tribute to Darwin's love of, and search for, truth, he added:

> that though many attacks have been made on religious truth in his name, he never made such himself. . . .
>
> I believe that such intellects as those which were given to Newton and to Darwin, were given for the purpose of being applied to the examination of the universe which God who gave the intellect created and made. But if I am told that because Newton discovered gravitation, therefore I can dispense with the Apostles' Creed, or that, having got the works of Darwin, I may leave my Bible, I reject the conclusion, not only as illogical and monstrous, but as contradicting a voice within me which has as much right to be heard as my logical understanding.[427]

He urged the Church to participate actively in the debate about "Modern Science and Vital Christianity", neither being afraid of scientific truths nor too hurriedly rejecting any as un-Christian. Rather, one should thank God to be living in such a century of progress. Yet sometimes low-technology solutions were best: at the Church Congress held in 1875, he lamented the difficulties faced by clergy of scattered rural parishes, and asserted that many "could find no better curate than a good stout pony." He also showed his concern for the least well-paid of his clergy by instituting a "Rest Fund" to give practical assistance to weary or sick preachers. In the cause of temperance, Goodwin was keen to enlist the aid of the publicans in refusing to sell alcohol to cus-

[426] Quoted in Rawnsley (1896), p.223.

[427] Quoted in Rawnsley (1896), p.224.

tomers who had been convicted three times for drunkenness. But, unsurprisingly, nothing seems to have come of it.[428]

In the House of Lords, he was active in trying to secure several pieces of new legislation concerning Church matters. Though many failed to reach the statute books, he had one major success with the establishment of a Royal Charter for a "Church House". Following up a suggestion from a friend, Goodwin proposed that, to mark Queen Victoria's Jubilee in 1887, a large meeting place should be constructed where clergy and laity could meet in assembly to discuss Church affairs. This "Chapter House for the whole English Church" received wide support and was ultimately realised, though not until after Goodwin's own death, as he had himself prophesied. It was built in the prime location of Westminster, close to the Houses of Parliament, and is still regularly used for its planned purpose.

Another successful project was the publication of a plain and brief summary of the common doctrine of all the Anglican Churches of the world, and how this relates to other churches and Christian societies. This was adopted by the Lambeth Conference of 1888. It is perhaps not inappropriate to think of this as the Anglican equivalent of Goodwin's own *Elementary Course of Mathematics*: both are short and clear statements of the irreducible core of their respective topics.

A huge number of Goodwin's sermons, lectures, addresses, theological essays and instructional works were published.[429] Among his more substantial publications are commentaries on the Gospels of Matthew, Mark and Luke, his Hulsean lectures on theology in Cambridge (1855), and a volume of *Essays on the Pentateuch* (1867). According to his biographer, Canon Rawnsley, Goodwin "had long felt that the exaggerated claims of scientific research to absolute accuracy and mathematical certainty in its results constituted a serious danger which required to be firmly met. . . . He therefore joined in the battle by an article on "Bees and Darwinism", which created a considerable stir in the scientific and theological world". Goodwin's lifelong searching for compromises between conflicting viewpoints is well illustrated by the following quotation:

> While the causes, assigned by Mr Darwin and Mr Wallace for the progressive character of nature are to be accepted as having much to do with that progress, there are deeper causes at work, without which natural selection and

---

428 Rawnsley (1896), pp.246, 293, 294.

429 A search of the COPAC database of British university libraries yields several hundred items.

> the struggle for existence would be found ineffectual in producing these results.[430]

This cautious view, combining evolution with divine oversight and control, is very much in line with the expressed beliefs of William Hopkins, George Gabriel Stokes and William Thomson.

In the same year of 1889 Goodwin published his most ambitious theological work, *On the Foundations of the Creed* (Goodwin 1889). Though well enough reviewed, it did not win the enthusiastic reception for which Goodwin had hoped. Here, too, there is a mathematical connection, for it is dedicated to his friend George Gabriel Stokes. In this, Goodwin again alluded to the connections of science, mathematics and religion:

> The doctrines of the Gospel of Christ cannot be proved in the same way as the truths of geometry, the theorems of algebra, the generalisations of physical science, or even the facts of history; were it so, there would be no place for faith, no demand for a creed. But, on the other hand, the profession of faith, the acceptance of a creed, means no treason to the intellect; and a man may have sounded all the depths of all the sciences and yet may say with perfect honesty and perfect simplicity, I believe in God the Father, God the Son, and God the Holy Ghost.[431]

Regarding theology, he advised in 1890 that: "It is well not to over-estimate the importance of any religious controversy which may happen to be stirred up in our own times." Citing earlier controversies which included those over *Essays and Reviews* and Colenso's writings, he pointed out that these had now fallen from view, that the panic had gone, and that fears for the faith and doctrine of the Church had been quite unjustified. Sober reflection in due time led to a deeper understanding and interpretation of the Bible in no way contradicted by modern science and literature.[432]

From about 1883, he suffered from angina of the heart and had to cut down on his physically demanding schedule. In the week before his death, he visited his friend John Ruskin, the artist and writer, who lived in Goodwin's diocese at Brentwood, near Coniston. Their shared interests in architecture and social

[430] From Goodwin's "Bees and Darwinism", quoted in Rawnsley (1896), p.315.

[431] From the Preface of Goodwin's *Foundations of the Creed*, quoted in Rawnsley (1896), p.316.

[432] Rawnsley (1896) pp.164, 165, 306.

welfare were doubtless a bond. He then returned to Carlisle to conduct Diocesan business, before travelling on to Bishopthorpe for discussions with the Archbishop of York. But there he suffered serious heart failure, and died a few days later, on 25 November 1891, at the age of seventy-three.

Harvey Goodwin personified the worthy but unspectacular attributes of steadfastness, common sense and balanced judgment without which the administration of no large organisation can function efficiently. He was an effective churchman, a practical and persuasive moderate. He cared more for the smooth running of the Church, its physical fabric and its music, and the well-being of the common people, than for high theological debate. Controversies had raged on reinterpreting the Bible in the light of new scientific discoveries, on the relation of Church and State, on the ritual of Church services and more. In them all, he acted to smooth differences and restore harmony. He administered a difficult and scattered diocese, winning the approval of most and making few enemies. He was a respected participant in Church Congresses; and he assiduously supported Parliamentary bills on Church affairs, though sometimes disappointed when they failed to become law. His outlook was well expressed in a Cambridge sermon:

> . . . I would not wish any one who has habitually attended the church to be able to say of me, "he belonged to this school or to that, or he preaches this doctrine or that": but rather this—"he endeavoured to teach us how thoroughly the religion of Christ was bound up with our every-day life and actions."[433]

[433] Rawnsley (1896), pp.93, 94.

9.
Universities and Colleges

Many top wranglers held key positions in English, Scottish and Irish universities and colleges, and some went overseas. Here, we review their contributions to each institution in turn.[434]

The English Universities and Colleges

Cambridge University and Its Colleges

Top wranglers graduating B.A. between 1829 and 1856 who spent more than just a few early years of their careers in Cambridge are shown in Table A of Appendix B, pp. 356–358. They are more than fifty in number. Just a few lower-ranked wranglers who went on to high office are included in the Table: even the eighteenth wrangler Henry Latham published a text on mathematics and became head of a college. Nearly all were fellows and tutors of their colleges; ten went on to become college heads, and several others held senior college appointments or were noted private tutors. Nine of the fifty became professors of the University in a range of subjects that encompasses mathematics, astronomy, physics, chemistry, physic (medicine), political economy, moral philosophy and divinity.

Though not all listed in the Table would have taught mathematics in their colleges, most did so at least for a time. And even the few who probably did not, such as Paget, Birks, Swainson and Fawcett, would have had well-informed views on the subject. Though some remained fellows of their colleges while

[434] The main source of biographical information is Venn & Venn (1940). Other sources are given in the notes. There is no complete register of nineteenth-century professors and other teaching staff in British universities and colleges. Histories of individual institutions are helpful but not comprehensive. This chapter goes some way towards providing an overview that may help future historians; but the account of so many individuals, eminent and obscure, has presented problems of exposition which are not resolved to the author's satisfaction.

absent elsewhere, the sheer numerical strength of mathematicians at Cambridge is apparent—and fellows and professors who obtained their B.A. degrees before 1829 or after 1856 are not included in the list. In contrast, at other universities and colleges, no more than two or three able mathematicians were employed at any one time. But whether Cambridge made appropriate use of such depth of talent, either in implementing a well-organised system of teaching or in encouraging research, is quite another matter.

After fourteen years as a lawyer and several unsuccessful applications for academic posts, Arthur Cayley in 1863 gladly accepted a considerable decrease in income to become Cambridge's first Sadlerian Professor of Pure Mathematics. No fewer than four of the eight applicants for this post were senior wranglers: Cayley, Todhunter, Ferrers and Routh. The three last were able teachers, whereas Cayley had little teaching experience. Before the appointment, Todhunter confided to George Boole that "I have . . . no objection to Mr. Cayley; but it is obvious that he cannot teach or explain anything"; but Cayley's research reputation was enough to secure the post. Cayley held this chair until his death in 1895, producing a stream of original work. But, as Todhunter had warned, he was a poor lecturer, and only a few particularly well-motivated students attended his courses.[435]

Cayley was without a doubt the finest and most prolific *pure* mathematician in Britain, in an age when applications of mathematics were paramount. Despite the shortcomings of his own teaching, Cayley had strong views on mathematical education. He objected to any modification of Euclid's *Elements* as the school geometry text *par excellence*, yet perversely believed that "the proper way to learn geometry is to start with the geometry of *n* dimensions and then come down to the particular cases of 2 and 3 dimensions."[436] When, in 1866–67, Sir George Biddell Airy complained to the Board of Mathematical Studies that his sons' education in Cambridge lacked appropriate emphasis on applications of mathematics, Cayley entered the debate, vigorously defending the intellectual value of studying pure mathematics for its own sake.[437]

---

435 Crilly (1999), pp.126, 127, 134; (2006) Ch.9, 10.

436 Crilly (1999), p.154.

437 Among the few who benefited from Cayley's courses, and who went on to contribute to pure mathematics, were William K. Clifford (2nd, 1867), James W.L. Glaisher (2nd, 1871), Richard Rowe (3rd, 1877), Andrew R. Forsyth (1st, 1881 and Cayley's successor), Henry F. Baker (1887) and Charlotte Scott (ranked equal to 8th wrangler in 1880, but not officially recorded). Other notables known to have attended his courses include James Stuart, Karl Pearson and J.J. Thomson. See Crilly (1999), pp.149–151, 153n; (2006) pp.357–361. Comprehensive studies of Arthur Cayley and his work are Crilly (1986; 1988; 1999; 2006).

But Airy's opinion carried much weight and, after due consideration, the Board reinstated several topics that had earlier been withdrawn, among them heat, electricity and magnetism.

Some years before Cayley's appointment, George Gabriel Stokes had secured the Lucasian chair in 1849, and John Couch Adams the Lowndian chair in 1859, both discussed in the preceding Chapter. Later, they were joined by James Clerk Maxwell as the first Cavendish Professor of Experimental Physics. Thereby, Cambridge gained the services of four truly outstanding researchers: Stokes and Maxwell in mathematical physics, Adams in theoretical astronomy, and Cayley in pure mathematics.

Many Cambridge wranglers took college appointments elsewhere in England: the list shown in Table B is long and probably incomplete, showing the extent of penetration of the "Cambridge style" among the other English universities and colleges. To emphasise Cambridge's continuing influence, some appointments up to the 1880s have been included.

Table B. Some Cambridge wranglers employed at other English colleges and universities (as professor if not otherwise specified)

University College, London: A. De Morgan (M 1828–31, 1836–67), G. Long (G 1828–31), H. Malden (G 1831–76), G.J.P. White (M 1831–36), J.J. Sylvester (NP 1838–41), R. Potter (NP&As 1841–43, 1844–65), B.T. Moore (E 1868–71), C.J. Lambert (M 1871–?), W.K. Clifford (AM 1871–79), L.H. Courtney (PoE 1872–75), R.C. Rowe (PM 1880–84), M.J.M. Hill (PM 1884–1907, M 1907–23)

King's College, London: T.G. Hall (M 1830–69), H. Moseley (NP & As 1831–44), J. Allen (LM 1832–39), G. Budd (Med 1840–63), M. O'Brien (NP 1844–54), T.M. Goodeve (E & NP 1853–60), H.W. Watson (LM 1857), J.C. Maxwell (NP 1860–65), G.R. Smalley (LNP 1862–63), W.G. Adams (LNP 1863–65, NP 1865–1905), A. Barry (Pr 1868–83), W.H. Drew (M 1869–82)

Royal Military Academy, Woolwich: S.H. Christie (Asst M 1806–37; M 1838–54), M. O'Brien (LAs 1849–54; M 1854–55), F.W. Vinter (MsM 1851–58), J.J. Sylvester (M 1855–70), T.M. Goodeve (AM & P 1860–?), F. Bashforth (AM 1864–72), W.D. Niven (M 1867–74), A.G. Greenhill (M 1876–1907), H. Hart (M ?–?)

Royal Military College, Sandhurst: G.W. Hearn (M 1839–51), F.W. Vinter (M 1858–72), B.T. Moore (M 1859–64), T. Savage (M ?–?)

Royal Naval College, Greenwich: W.D. Niven (M 1882–1903), J.H. Cotterill (Applied Mechanics 1873–97), R.K. Miller (AM 1873–75), C.J. Lambert (M ?–?), W. Burnside (M 1885–1919)

Table B. *Continued*

Royal Greenwich Observatory: G.B. Airy (Astronomer Royal 1835–81), R. Main (Chief Asst 1835–59), E.J. Stone (Chief Asst 1860–70), W.H.M. Christie (Chief Asst 1870–80, Astronomer Royal 1881–1910)

Government School of Mines (later Roy. Coll. of Science), S. Kensington: G.G. Stokes (P 1854–60), A.S. Herschel (P 1861–66), T.M. Goodeve (M & mechanics 1869–94)

Hon. East India Company College, Haileybury: J.W.L. Heaviside (M 1838–57)

Royal Indian Engineering College, Cooper's Hill: J. Wolstenholme (M 1871–89), E.J. Nanson (M 1874?), A.G. Greenhill (AM 1872–73)

Engineering College, Putney: B.M. Cowie (Pr 1844–51)

London College of Divinity: T.P. Boultbee (Pr 1863–84)

Owen's College, Manchester: A. Sandeman (M & NP 1851–60; M 1860–65), R.B. Clifton (NP 1860–66), T. Barker (M 1865–85), W. Jack (NP 1866–70), O. Reynolds (E 1868–1905), J.E.A. Steggall (LM 1880–83), A. Schuster (AM 1881–88, P 1888–1907), H. Lamb (M 1885–1920)

Oxford University and colleges: R. Main (As: Radcliffe Observer 1860–78), R.B. Clifton (ExP 1866–1921), E.J. Stone (As: Radcliffe Observer 1879–97), C. Pritchard (As 1870–93), J.J. Sylvester (M 1884–92), A. Marshall (F Balliol 1882–85)

Durham University: J. Carr (M 1833), T. Chevallier (M 1835–71, As 1841–71), R.J. Pearce (M 1874–95), C.T. Whitley (RNP&M 1833–55)

Durham College of Science, Newcastle: W.S. Aldis (M 1871–84; Pr 1879–84), A.S. Herschel (P 1871–86), W. Garnett (Pr 1884–93)

Royal Naval College, Portsmouth: T.J. Main (M 1846–71)

Mason's College, Birmingham: M.J.M. Hill (M 1880–84)

Bristol University College: A. Marshall (PoE & Pr 1877–81)

Liverpool Collegiate Institute/University College: J. Porter (AsstM 1851–55), A.R. Forsyth (M 1882–83)

University College of Wales, Aberystwyth: R.W. Genesé (M 1879–1919)

AM = applied mathematics, As = astronomy, Asst = assistant, E = engineering, ExP = experimental philosophy, F = fellow, G = Greek, L = lecturer, M = mathematics, Med = medicine, Ms = master, NP = natural philosophy, P = physics, PM = pure mathematics, PoE = political economy; Pr = principal, R = reader.

University College, London

Outside Cambridge, the first professor of mathematics at the newly founded London University—later University College, London—was Augustus De Morgan (4th, 1827), appointed at the tender age of twenty-one. He went on to become one of the foremost mathematicians of his time, an acclaimed teacher and a first-rate researcher.[438] Though an exact contemporary of Hopkins at Cambridge, De Morgan seems to have had little direct contact with him, either then or afterwards. Accordingly, De Morgan's appearance in this book is more marginal than his reputation warrants. But he certainly had a favourable opinion of Hopkins as a teacher, for he recommended him to students who went on to Cambridge.[439]

In 1838, De Morgan was joined at University College London by John Joseph Sylvester (2nd, 1837), who became professor of Natural Philosophy at the age of twenty-three, soon after finishing at Cambridge. (Sylvester had briefly studied at London University as a fourteen-year-old student in 1828, when he was a member of De Morgan's very first class; but he was withdrawn after just five months, having allegedly attacked a fellow student with a table knife following an insult.) Others who benefited from De Morgan's instruction before they proceeded to Cambridge were Edward Routh and Isaac Todhunter. De Morgan resigned his chair in 1831 in protest over the dismissal of a colleague, and he was replaced by George James Pelly White (6th, 1829). But when White died in a drowning accident in 1836, De Morgan was reappointed.[440]

Sylvester did not enjoy his position in London, and resigned in 1841 to take up a professorship of mathematics at the University of Virginia, Charlottesville, U.S.A. There, he stayed only a few months, quarrelling with the authorities over what he viewed as inadequate support in a disciplinary matter involving a student.[441] In 1844, he was back in London, working as an actuary

---

438 Rice (1997; 1999); Panteki (2003).

439 For instance, De Morgan wrote to the father of Alexander Gooden, suggesting that his son contact Hopkins. Though Hopkins agreed to take on Gooden, the latter decided to concentrate on classics, and instead studied mathematics with the less-challenging J.W.L. Heaviside (Smith & Stray 2003, p.69).

440 Another who resigned for the same reason in 1831 was the first Professor of Greek, George Long, in 1822 senior Chancellor's medallist in Classics (and 30th and last wrangler). The Greek chair was then held for forty-five years by Henry Malden, a Cambridge contemporary of Long and junior Chancellor's medallist. Malden played a major part in the delicate negotiations over the founding of the over-arching University of London.

Sylvester's predecessors in the chair of Natural Philosophy were the rumbustious Irishman, Dionysius Lardner (1828–31) of *Cabinet Cyclopaedia* fame, and the Scot William Ritchie (1832–37), who had studied at Edinburgh and Aberdeen and lectured for a time at the Royal Institution in London.

441 An often-quoted story that Sylvester fled back to Britain, wrongly believing that he had killed the said student with his sword-stick, is incorrect. The sole original source is clear that Sylvester slightly wounded a student in self-defence: his sudden departure was more likely attributable to fear of further violence. See Parshall (2006), pp.73–76.

and studying law at the Inner Temple, and meeting regularly with Arthur Cayley to discuss mathematics. From 1855 to 1870, Sylvester then held the professorship of mathematics at the Royal Military Academy in Woolwich until, again at odds with the authorities, he was forced into early retirement at the age of fifty-five.[442]

After five desultory years, Sylvester returned to the United States in 1876 as mathematics professor at the newly opened Johns Hopkins University in Baltimore. There, he did much to establish a research ethos, founding and editing the *American Journal of Mathematics*. Harvard's professor Benjamin Peirce had warned that, despite his brilliance, Sylvester's "power of teaching will probably be said to be quite deficient. . . . [A]s the barnyard fowl cannot understand the flight of the eagle, so it is the eaglet only who will be nourished by his instruction."[443] But Sylvester had assistants to teach the elementary classes, and he succeeded in motivating several students and junior colleagues to undertake original research under his guidance.

Sylvester spent eight productive years at Johns Hopkins, then returned to England in 1884, aged sixty-eight, to end his career as Oxford's Savilian Professor of Geometry. But, after the freedom he had enjoyed at Johns Hopkins, he found it hard to adjust to undergraduate teaching and Oxford's lack of commitment to research; and failing health and the unpopularity of his lectures led to his resignation in 1892.[444]

Sylvester's replacement at University College, London was Richard Potter (6th, 1838), who served as Professor of Natural Philosophy and Astronomy from 1841 to 1865, apart from the year 1843–44 spent at King's College, Toronto. Unfortunately, his competence as an experimentalist, mainly in optics, was not matched by any ability as a teacher. He wrote textbooks on mechanics, on optics, and on hydrostatics and hydrodynamics. But he was notorious for getting into a muddle unless he copied his lecture notes verbatim from textbook to blackboard.[445] With Potter's departure in 1865, two chairs, of Mathematical Physics and of Experimental Physics, were created. The Germany-educated Thomas Archer Hirst was appointed to the former, then succeeded to De Morgan's chair two years later. The experimental chair went to a University College alumnus, G. Carey Foster. Around the same time, Benjamin Theophilus Moore (8th, 1856) was recruited as Professor of Civil

442 Parshall & Rowe (1994), pp.62–71; Parshall (2006), Ch.4, 6, 7.

443 Quoted in Parshall & Rowe (1994), p.73.

444 See Parshall (2006), Ch.9–11.

445 One listener concluded that Potter "had lost his memory and not a few of his wits": Bellot (1929), p.263.

Engineering and Applied Mechanics, following a period as Professor of Mathematics at the Royal Military College, Sandhurst. William Kingdon Clifford (2nd, 1867) held the applied mathematics chair for some eight years; the short-lived Richard Rowe (3rd, 1877) was professor of pure mathematics during 1880–84; and his successor Micaiah J.M. Hill (4th, 1879) served from 1884 to 1923, after a few years at Mason's College, Birmingham. Hirst, Clifford and Hill were particularly active in research.

King's College, London

At King's College London, Thomas Grainger Hall (5th, 1824) was appointed to the chair of Mathematics in 1830, "which he continued modestly, faithfully, and inconspicuously to occupy (rather than fill) for the next thirty years [in fact 39 years]. He wrote a few forgotten textbooks and rose to be a prebendary of St Paul's."[446] His former student Walter Besant complained that by 1854 Hall "was old and had quite lost all interest in his work."[447] Nevertheless, in earlier days, he had published a worthy calculus text, and he gave his students, including the young Arthur Cayley, a thorough mathematical grounding. He was assisted for a time by John Allen (18th SO), who was both a lecturer and college chaplain.[448] Henry Moseley (7th, 1826) was the Professor of Natural and Experimental Philosophy and Astronomy during 1831–44, and published rather pedestrian works on hydrostatics and mechanics. He then served from 1844 to 1853 as H.M. Inspector of Schools before taking a church living in Gloucestershire.

The Irishman Matthew O'Brien (3rd, 1838) succeeded Moseley as Professor of Natural Philosophy and Mathematics during 1844–54; and, from 1849 to 1854, he simultaneously held the post of lecturer in astronomy at the Royal Military Academy, Woolwich. He resigned from King's College in 1854 on being appointed Professor of Mathematics at Woolwich in preference to J.J. Sylvester and G.G. Stokes; but he died the following year, aged only forty-one, and Sylvester then succeeded him. An able mathematician, O'Brien wrote several textbooks, and might well have achieved more in research had he not been overburdened with teaching.

Also at King's College, London for a time was James Clerk Maxwell (2nd, 1854), who held the Chair of Natural Philosophy from 1860 until 1865, after having to leave his post in Aberdeen. Though a brilliant researcher who could

[446] Hearnshaw (1929), pp.88, 89.

[447] Besant (1902); see also Chapter 2, p.20.

[448] See also Crilly (2006), pp.17–26.

inspire able and dedicated students, Maxwell was clearly ineffective as a teacher of those less able and less dedicated. According to one source, he was unable to keep his classes in order, and was eventually asked to resign; but the scanty hearsay evidence for the latter is untrustworthy.[449]

George Robert Smalley (28th, 1845) was appointed as a lecturer to assist Clerk Maxwell, but remained for just a year, before emigrating to Australia to become Director of the Sydney Observatory (see Chapter 10). Smalley's replacement was William Grylls Adams (12th, 1859), younger brother of John Couch Adams: he spent two years as a lecturer, before succeeding Maxwell as Professor of Natural Philosophy in 1865. The *King's College Annual Report* of April 1862 had noted that "The increase of numbers in the Department has made it necessary to lighten the labours of the Professor of Natural Philosophy" by appointing Smalley as the first lecturer. And Maxwell himself wrote to his friend Lewis Campbell, Professor of Greek at St Andrews, that:

> I hope you enjoy the absence of pupils. I find that the division of them into smaller classes is a great help to me and to them; but the total oblivion of them for definite intervals is a necessary condition of doing them justice at the proper time.[450]

The probable reasons for Maxwell's resignation were that he did not much enjoy teaching, and wished for more time for research. Having little need of the salary, he withdrew to his Scottish residence at Glenlair, where he could work in peace. Nevertheless, some of his best work had been done in London. A few years on, he was encouraged to apply for the Principalship of the United Colleges at St Andrews, in succession to J.D. Forbes. But he eventually decided not to stand, informing Lewis Campbell that "I still feel that my proper path does not lie in that direction."[451]

During W.G. Adams' long tenure of the King's College chair, he developed laboratory facilities and gave his teaching a decidedly practical slant, benefiting the prospective engineers that the college increasingly recruited. His teaching laboratory, founded in 1868, was the first in Britain where *all*

[449] The allegation is made in Hearnshaw (1929), p.248, based on two letters from the Rev. Canon Richard Abbay. The matter is carefully re-examined by Domb (1980), who concludes that Hearnshaw's account "should be completely discounted".

[450] The College Report is quoted in Domb (1980) p.71. The Maxwell letter to Campbell is in Campbell & Garnett (1882), p.336; also Harman (1990–2002).

[451] Letter to Lewis Campbell, 3 Nov. 1868: in Campbell & Garnett (1882), pp.345, 346; also Harman (1990–2002).

students gained experience of practical physics. (The earlier laboratories of W. Thomson in Glasgow and of J.D. Forbes and then P.G. Tait in Edinburgh were restricted to a few hand-picked individuals.) Adams' own research interests were mainly in magnetism and optics.

Five others who had connections with the college were George Budd (3rd, 1831), Thomas Minchin Goodeve (9th 1843), Arthur Barry (4th, 1848), William Henry Drew (8th, 1849) and Henry William Watson (2nd, 1850).

George Budd did not pursue mathematics after graduation, but instead turned to medicine. He came from a medical family, and his surgeon father had nine sons, seven of whom went on to practice medicine. Five of the brothers attended Cambridge, and all five were wranglers.[452] After study in Paris and at Middlesex Hospital in London, George Budd first joined the Navy Hospital Ship at Greenwich. From 1840 to 1863, he was Professor of Medicine at King's College and physician at King's College Hospital, while also pursuing a successful private practice. He was a leading authority on the cause of scurvy and on liver diseases, his text *On Diseases of the Liver* (1845) being highly regarded.

Thomas Goodeve had been a student at King's College, London in 1839–40, and was tipped to be second wrangler at Cambridge in 1843 behind John Couch Adams; but he gained only ninth place, having fled in panic after three days of examinations. Goodeve held several appointments in the London colleges. It seems that he was already in the King's College mathematics department when he succeeded the College's professor of manufacturing, art and machinery in 1852; and he also took over the natural philosophy chair in 1854 when O'Brien left for Woolwich. But rewards at the struggling King's College were no match for the government salaries at the Military Colleges and the School of Mines, and Goodeve left for Woolwich around 1860. In 1869, he became Professor of Mathematics and Applied Mechanics at the Government School of Mines, and until 1894 he remained a lecturer in mechanics and mathematics at its successor, the Royal College of Science. He may have continued to hold his Woolwich appointment simultaneously. He wrote several texts on mechanics.

Arthur Barry eventually went to Australia on being appointed Bishop of Sydney. But, before then, he held successive teaching and administrative posts in several prestigious schools.[453] From 1868 to 1883, he was Principal of King's College, London. There, he energetically reorganised the college

---

452 Charles Octavius Budd (3rd, 1840) was one who did not study medicine.

453 He was subwarden at Trinity College, Glenalmond, Headmaster of Leeds Grammar School, and Principal of Cheltenham College.

administration, relaxed the rules of strict religious observance, and modernised the teaching of engineering and medicine. He was also a strong supporter of higher education for women.[454]

Though H.W. Watson spent most of his life as an Anglican rector in Warwickshire, he was briefly a Cambridge fellow, a mathematics lecturer at King's College, London and a mathematics master at Harrow School. Much influenced by Clerk Maxwell and a collaborator of Francis Galton, he maintained an active interest in science and wrote several textbooks.

W.H. Drew held the mathematics chair from 1869 until his death in 1882. From 1856, he had taught at Blackheath Proprietary School, and became its Principal in 1867, continuing in that role until 1873 despite his King's College appointment. His textbook on *Geometrical Conic Sections* was well known in its day.

The Military and Naval Colleges

The appointments of M. O'Brien, J.J. Sylvester and T.M. Goodeve at the Royal Military Academy, Woolwich have already been mentioned. An earlier appointee was Samuel Hunter Christie (2nd, 1805), who worked at the college as Assistant and later Professor of Mathematics for almost fifty years. Others who taught at the college include Francis Bashforth (2nd, 1843) and William Davidson Niven (3rd equal, 1866).

Bashforth spent a few years as a fellow of St John's College, Cambridge. In 1857 he became rector of a parish in Lincolnshire, a post which he held (perhaps as a sinecure) until 1908 along with other appointments. After gaining practical experience as a surveyor with a railway company, in 1864 he was appointed Professor of Applied Mathematics at the Royal Military Academy, Woolwich. There, his duties included teaching ballistics to trainee artillery officers, and these led him to conduct experimental and theoretical researches on the air resistance of projectiles. He resigned from the Academy in 1872 but continued as an advisor to the Government.

W.D. Niven was the Academy's Professor of Mathematics during 1867–74. He then returned to Trinity College, Cambridge for a time, before becoming Professor of Mathematics at the Royal Naval College, Greenwich, where he remained from 1882 until 1903. Niven's long-term successor at Woolwich was Alfred George Greenhill (2nd, 1870), an able analyst who wrote several textbooks and pursued research on the uses of elliptic functions in fluid mechanics and elasticity. Also there for a time was Harry Hart (4th equal, 1871).

---

454 Hearnshaw (1929), Ch.IX.

At the Royal Military College, Sandhurst, as at the Royal Military Academy, Woolwich, Cambridge graduates came to dominate appointments in mathematics and physics from the 1840s onwards, though few Cambridge men had been employed by these colleges before that time. Wranglers appointed to teach mathematics at Sandhurst include George Whitehead Hearn (6th, 1839), Frederick William Vinter (3rd, 1847), Benjamin Theophilus Moore (8th, 1856) and Thomas Savage (2nd, 1857). Similarly, the Royal Naval College, Greenwich employed several wranglers: W.D. Niven, C.J. Lambert (3rd, 1867), Robert K. Miller (aegrotat 1867 and 1st Smith's Prize), William Burnside (2nd equal, 1875) and James Henry Cotterill (19th, 1863), the last of whom had previously taught at London's Royal School of Naval Architecture. Of these, Burnside was the most productive and original mathematician, making important contributions in several areas, including group theory and probability.

Durham University and Durham College of Science, Newcastle

At Durham University, the first Professor of Mathematics was John Carr (2nd, 1807), a former fellow of Trinity College who had been headmaster of Durham School since 1811. He was appointed to the chair in June 1833, but died in October, just two days after his first term had begun. In contrast, the next professor, Temple Chevallier (2nd, 1817), held the post from 1835 until 1871. He had previously been a fellow of St Catharine's College, Cambridge. Responsibility for astronomy was added to his mathematics chair in 1841; he held the additional post of Reader in Hebrew during 1835–71; and he was Registrar of the University for 1835–72. He published several papers on astronomy and physics, as well as religious works. He was succeeded in 1873 by Robert John Pearce (3rd, 1864).

From 1833 until 1855, the Reader in Natural Philosophy at Durham was Charles Whitley, the 1830 senior wrangler from St John's College and a close student friend of Charles Darwin. Whitley was also active in the Church, as an honorary canon of Durham (1849–95) and chaplain to the Bishop of Newcastle (1883–95). He published a mechanics text, *Outlines of a New Theory of Rotatory Motion from the French of Poinsot, with Explanatory Notes.*[455]

In 1871, the physically separate Durham College of Science at Newcastle upon Tyne (precursor of Newcastle University, but then part of Durham University) employed another senior wrangler, William Steadsman Aldis (1st,

[455] Fowler (1904); Whiting (1932); Venn & Venn (1940).

1861), as Professor of Mathematics. From 1879 to 1884, he was the College's Principal, then resigned to become Professor of Mathematics at University College, Auckland, New Zealand.

The first Professor of Physics at the Durham College in Newcastle was Alexander Stuart Herschel, son of (Sir) J.M.W. Herschel and a mere twentieth wrangler in 1859. He served from 1871 until 1886, and continued as an honorary professor until 1907. Inheriting the family interest in astronomy, he did notable work on meteors and comets. He is also linked with another astronomer, Charles Pritchard, who was Herschel's headmaster at Clapham Grammar School before gaining an Oxford professorship. As a Cambridge undergraduate, Herschel had assisted Clerk Maxwell. A longer-term associate (and biographer) of Maxwell was William Garnett (5th equal, 1873), who was Maxwell's main experimental assistant and lecturer in physics in Cambridge. Disappointed not to succeed Maxwell, he was briefly a professor at the new Nottingham University College, then Principal of the Durham College from 1884 until 1893.[456]

Owen's College, Manchester

At Owen's College, Manchester, Archibald Sandeman (3rd equal, 1846) was the first professor of Mathematics and Natural Philosophy during 1851–60. When the chairs were separated, Robert Bellamy Clifton (6th, 1859; 2nd Smith's Prize) became the College's first Professor of Natural Philosophy from 1860 until 1866, while Sandeman continued to hold the Mathematics chair until 1865. The Professor of Mathematics during 1865–85 was Thomas Barker (1st, 1862), who had first studied at Aberdeen. When Clifton was elected Professor of Experimental Philosophy at Oxford in 1866, he was succeeded by William Jack, fourth wrangler in 1859 and a Glasgow graduate. From 1868 to 1905, the Professor of Engineering at Owen's College was Osborne Reynolds (7th, 1867), Irish-born but Cambridge educated. During 1880–83, John E.A. Steggall (2nd, 1878) was briefly a lecturer in mathematics, before moving to Dundee.

Arthur Schuster was a professor at Owen's College from 1881–1907. Though he had enrolled at St John's College, Cambridge in 1876, he did not complete his B.A. degree, instead becoming an assistant to Clerk Maxwell. He received an honorary Sc.D. from Cambridge in 1904. And the eminent fluid dynamicist, Horace Lamb (2nd, 1872), held the chair of mathematics from 1885 to 1920, following his return from Adelaide University.[457]

---

456 Whiting (1932); Knight (2004).

457 Charlton (1951).

Oxford University and Its Colleges

R.B. Clifton held his Oxford post until his death in 1921. Though he published just one research paper during his long time at Oxford, he was instrumental in securing funding for, and designing, the Clarendon Laboratory, which later played so influential a part in British physics. Also at Oxford were the astronomers Charles Pritchard (4th, 1830) and Robert Main (6th, 1834). After a career as an enterprising headmaster of grammar schools, Pritchard became Savilian Professor of Astronomy at the age of sixty-two. He held this chair from 1870 to 1893, supervising the building of a new Savilian Observatory and pioneering the use of stellar photography (though all observations were made by assistants, not Pritchard himself). Robert Main was the elder brother of Thomas John Main (1st, 1838), and spent twenty-five years as George Airy's chief assistant at the Royal Greenwich Observatory. Main then held the Oxford post of Radcliffe Observer from 1860 up to his death in 1878. There, he issued the first two volumes of the *Radcliffe Star Catalogue* and sixteen volumes of *Radcliffe Observations*.[458] He was succeeded by another Cambridge wrangler, Edward James Stone (5th, 1859).

Of Cambridge wranglers, only Pritchard, Sylvester and Clifton held professorial posts at Oxford. There, the level of mathematics teaching had been poor before Baden Powell's appointment to the Savilian chair of Geometry in 1827. He made organisational improvements; and he wrote on optics, about which he regularly corresponded with Airy, Stokes and William Rowan Hamilton. But he is better known for a non-mathematical publication, his contribution to the theologically controversial *Essays and Reviews*: he was the first well-known churchman to give strong support to Darwin's work on *The Origin of Species*.[459] Also prominent in Oxford mathematics were Powell's successor Henry J.S. Smith; Bartholomew Price, mathematical lecturer and tutor, then Sedleian Professor of Natural Philosophy (1853–98) and college head; Charles Lutwidge Dodgson, fellow of Christ Church; and Pritchard's predecessor as Professor of Astronomy, William Fishburn Donkin.[460]

Other Institutions

Situated near the Royal Naval College, Greenwich was the Royal Greenwich Observatory, where the senior positions were long the exclusive preserve of

458 Fox (2004a); Clerke (2004a,b).

459 Discussed in Chapter 7, pp.160, 161.

460 Fauvel, Flood & Wilson (2000).

Cambridge wranglers. George Biddell Airy (1st, 1823) and William Henry Mahoney Christie (4th, 1868) successively occupied the post of Astronomer Royal for seventy-five years. Christie had been Airy's last chief assistant; and his previous assistants Robert Main (6th, 1834) and Edward James Stone (5th, 1859) both later served as Radcliffe Observer at Oxford.

James W.L. Heaviside (2nd, 1830) spent much of his career at the College of the Honourable East India Company at Haileybury, training young recruits for colonial service. He was its Professor of Mathematics during 1838–57, and its Registrar for 1850–57: the College then closed, when the H.E.I.C. was replaced by the Indian Civil Service. Heaviside was also a mathematical tutor to the royal Prince Arthur. Later, he served the Church as Canon of Norwich, a post which he held from 1860 until his death in 1897 at the age of eighty-nine. It seems that he published nothing, on mathematics or anything else.

Also involved in training young men bound for India was Joseph Wolstenholme (3rd, 1850). On his marriage in 1869, he had to resign his fellowship at Christ's College, Cambridge; then from 1871 to 1889 he was Professor of Mathematics at the Royal Indian Engineering College at Cooper's Hill, London. According to his friend Leslie Stephen, Wolstenholme had gone to Coopers Hill because his "Bohemian tastes and heterodox opinions had made a Cambridge career inadvisable": one of these tastes was for smoking opium.[461] Also there briefly were Edward John Nanson (2nd, 1873) and Alfred George Greenhill (2nd, 1870); but Nanson soon left for Australia and Greenhill for Cambridge and then Woolwich.

At the newly formed Bristol University College, the statistician and economist Alfred Marshall (2nd, 1865) was both Principal and Professor of Political Economy during 1877–81. Then, during 1882–85, he was a fellow of Balliol College Oxford, before succeeding Henry Fawcett as Cambridge's Professor of Political Economy. In Wales, the recently founded University College, Aberystwyth appointed R.W. Genesé (8th equal, 1871) as Professor of Mathematics.[462]

The career of Benjamin Morgan Cowie (1st, 1839) alternated between education and the church. He was Principal of the Engineers' College in Putney during 1844–51, Professor of Geometry at Gresham College in 1855, a minor canon of St Paul's Cathedral (1856–72) and simultaneously vicar of a London

[461] Stephen (1977), p.79; Barrow-Green (2004).

[462] The College opened in 1872 and, like several other institutions, its students were at first awarded external degrees from the University of London. It received its own charter in 1889. Genesé had previously been Vice-Principal of Carmarthen Training College.

parish. In 1872, he moved to Manchester as dean of Manchester Cathedral. There, he helped to establish the Manchester High School for Girls in 1874, and he was also involved with Owen's College. A few women had been admitted to certain classes at the College during 1875–76; and in the following year Cowie led an unsuccessful campaign for their full admission.[463] His last seven years were spent as Dean of Exeter. He wrote several scientific works and compiled catalogues of important library collections.

Thomas John Main (1st, 1838) served as both Chaplain to the Royal Navy and Professor of Mathematics at the Royal Naval College, Portsmouth (1846–71). James Porter (9th, 1851) was for a time an assistant in mathematics at the Collegiate Institute, Liverpool before returning to Cambridge. And Joseph Bowstead (2nd, 1833) became a barrister, but from 1860 served the cause of education as Inspector of Men's Training Colleges in England and Wales.

The London College of Divinity, established at St John's Wood in 1863, had as its first Principal Thomas Pownall Boultbee (5th, 1841). Boultbee was a fellow of St John's College, Cambridge for a few years until his marriage, and had been chaplain and divinity tutor at Cheltenham College under its headmaster Arthur Barry (4th, 1848). Boultbee served as Principal until 1884, at first with few students and assisted only by his wife and one other member of staff; but numbers later grew to a respectable level. The College was founded to address a perceived crisis of recruitment to the ministry of the Church of England, following publication of Darwin's *Origin of Species* (1859) and the furore provoked by *Essays and Reviews* (1860). Fewer young men in the universities were choosing to train for the ministry; and conservative churchmen viewed with suspicion the beliefs of some who did so—which might be tainted by the Oxbridge authors of *Essays and Reviews*, dubbed the "Seven against Christ". The College, with Church support, sought to recruit students from a wider field, such as "the families of the mercantile community and the higher class of tradesmen", who normally did not attend the Universities of Oxford or Cambridge. As well as divinity, the College provided instruction in other subjects, including mathematics, to prepare students to take London University degrees.[464]

Other Scientists and Mathematicians

Some other mathematicians active in England and *not* educated at Cambridge deserve mention. The geometer Thomas Archer Hirst studied

463 Charlton (1951), p.158.

464 Davies (1963), pp.17, 18.

mathematics and physics at several universities in Germany, then worked for a time in England as a schoolteacher. From 1865 to 1870, he was at University College, London; then from 1873 to 1883 he was the first director of studies at the Royal Naval College, Greenwich. Another notable individual was the Irish-born Francis Ysidro Edgeworth (1845–1926): educated in classics at Trinity College, Dublin and at Oxford, he then trained in law and was admitted to the Inner Temple in 1877 but did not practice. Instead, he turned his attention to mathematics, statistics and political economy. From 1888 to 1891, he served as Professor of Political Economy at King's College, London; and from 1891 to 1922 was Oxford's Drummond Professor of Political Economy and a fellow of All Souls College.

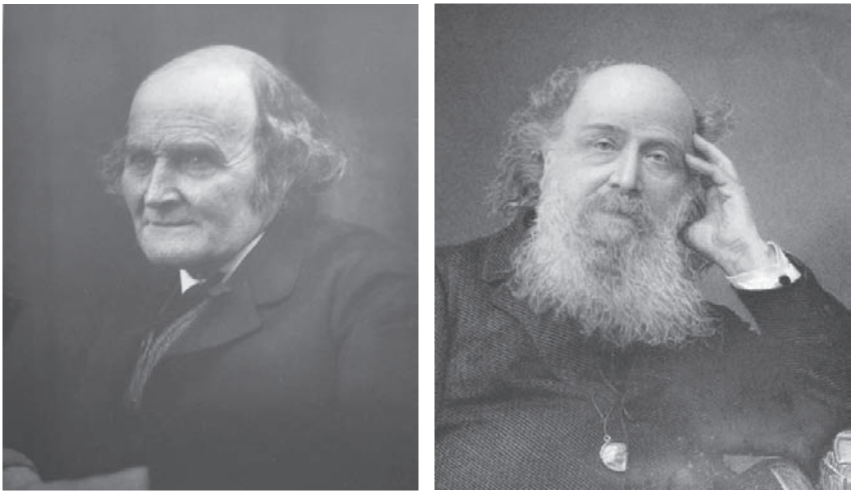
Also, one must not forget the contributions of gentlemen scholars who had no need of paid employment, and of curates, vicars and rectors of county parishes who had light duties and ample time for private study. In the latter category were Brice Bronwin and Thomas Penyngton Kirkman, who made worthwhile contributions to both pure and applied mathematics. One who combined mathematical research with running a successful business was Oxford-educated William Spottiswoode: while managing a major family-owned printing house, he published papers on geometry and applied mathematics, and served for five years as president of the Royal Society. The geneticist and biostatistician Francis Galton (poll degree, 1844) was sufficiently wealthy not to seek a paid academic post; but he played an active part in several scientific societies, and devoted his life to research, single-handedly founding the discipline of biometrics. His bequest to University College, London established the Galton Laboratory for National Eugenics and the Galton Eugenics Professorship: this chair was first held by Karl Pearson (3rd, 1879), who established University College as a major centre of statistical research.

The naturalist Charles Darwin also came from a very wealthy family; and, unlike his cousin Francis Galton, he felt under no pressure to succeed at university. He had recoiled from the rigours of the medical course in Edinburgh; then at Cambridge he aimed only for a poll degree, which he achieved in 1831, studying botany under the personal guidance of John Stevens Henslow. Darwin's voyages were partly funded by his family: these eventually led to his theory of evolution by natural selection that heralded a scientific revolution and a theological crisis.

William Cavendish (2nd, 1829), though not a creative scientist like his famous ancestor Henry Cavendish, was a major benefactor of science and higher education. As seventh Duke of Devonshire, he served as Chancellor of Cambridge University during 1862–91; and, through his munificent bequests, he was a key figure in the development of science at Cambridge. One can imagine the delight of Cambridge's Vice-Chancellor on receiving from him the following letter in 1870:

> I find in the report . . . of the Physical Sciences Syndicate, recommending the establishment of a Professor and Demonstrator of Experimental Physics, that the buildings and apparatus required for this department of science are estimated to cost £6300. I am desirous to assist the University in carrying this recommendation into effect, and shall accordingly be prepared to provide the funds required for the building and apparatus, so soon as the University shall have in other respects completed its arrangements. . . .[465]

So was born the famous Cavendish Laboratory. William Cavendish was also the first Chancellor of the University of London (1836–56), and a generous benefactor of Owen's College, Manchester.



a **b**

Figure 12. Portraits of A. Cayley, J.J. Sylvester, G.G. Stokes, W. Thomson, P.G. Tait, J.C. Maxwell. **(a)** Photograph by A.G. Dew-Smith, c.1890. **(b)** Engraving by G.J. Stodart from a photograph by I. Stilliard & Co., Oxford, c.1885 (published in *Nature 39*, 1889). (Courtesy of School of Mathematics and Statistics, University of St Andrews.) **(c)** 1892 photograph by Mrs F.W.H. Myers. [From Stokes (1880–1905), frontispiece to v.5.] **(d)** 1897 photograph by Annan, Glasgow (detail). [From Thompson (1910), frontispiece to v.1.] **(e)** P.G. Tait [From Tait (1898), frontispiece to v.1.] **(f)** Engraving by G.J. Stodart from photograph by Fergus of Greenock. [From Maxwell (1890), frontispiece to v.1.]

[465] Extract from University Papers E.A. 65, quoted in Winstanley (1947), p.196.

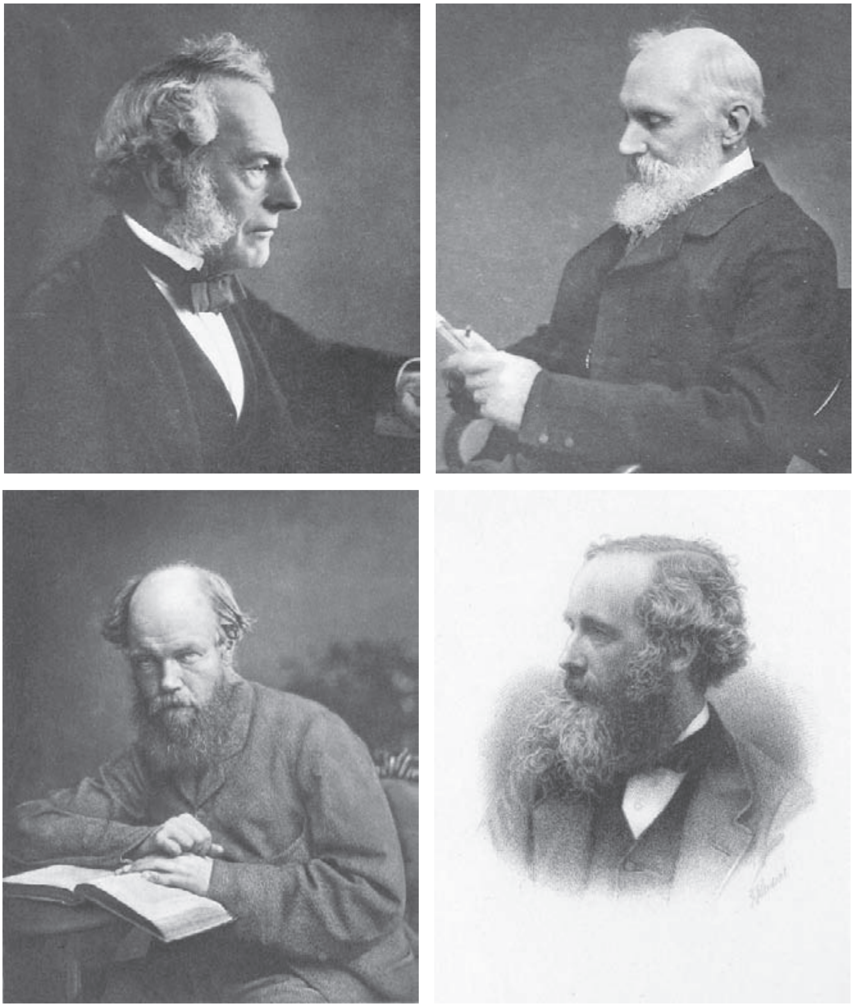


Figure 12. *Continued*

The Scottish Universities

Before Philip Kelland’s 1838 appointment to the Chair of Mathematics at Edinburgh University, all previous incumbents had been Scots for the most part educated in Scotland. The English-born Kelland, senior wrangler in 1834, was preferred over the Cambridge-based Scot, Duncan Farquharson Gregory

(5th, 1837) and able local applicants Edward Sang and John Scott Russell.[466] His appointment was in part a political one, engineered by Edinburgh's Professor of Natural Philosophy, the Tory J.D. Forbes. In this, as already noted, Forbes enlisted the support of William Hopkins, and Kelland's appointment was crucial in bringing Edinburgh's teaching somewhat closer to that at Cambridge. From this date, Cambridge graduates began to dominate appointments to the Scottish Chairs of Mathematics and of Natural Philosophy, and Cambridge's influence in these subjects grew.

In 1841, James Thomson, father of William Thomson and Professor of Mathematics at Glasgow University, began searching for suitable candidates to replace the aged and ailing William Meikleham as Glasgow's Professor of Natural Philosophy. He favoured the strong mathematical training that Cambridge offered, but Glasgow's religious tests required candidates to affirm their belief in the doctrines of the Presbyterian Church of Scotland, which few Anglicans were willing to do. By then, David Thomson (no relation) was a substitute lecturer in place of Meikleham. A Glasgow graduate who went on to Trinity College, Cambridge, David Thomson obtained only a lowly Tripos place in 1839, as 21st Senior Optime. James Thomson clearly wished for better, and considered three other Scots as possible candidates: Duncan F. Gregory and Archibald Smith, who had both studied at Cambridge as well as in Scotland, and James D. Forbes of Edinburgh.

He enlisted his son to report on Gregory's talents, and William wrote approvingly, but James Thomson remained doubtful of Gregory's aptitude for popular teaching. In the event, Gregory's health failed in 1843 and he died the next year, aged only thirty. The aristocratic Forbes, much influenced by the élitist educational philosophy of William Whewell, was deemed too out of sympathy with the democratic traditions of Glasgow University. Though still considering Archibald Smith, who by then had embarked on a law career, James Thomson also approached William Hopkins. However, both Smith and Hopkins seemed content with their current situations and so were thought unlikely to canvass energetically for the Glasgow post. By 1843, Thomson had come to the view that his own eighteen-year-old son would soon be a strong candidate. When Meikleham finally died in 1846, a campaign was carefully orchestrated and William Thomson (2nd, 1845) was unanimously elected at the age of twenty-two.[467]

---

[466] Davie (1961), pp.118–123.

[467] Smith & Wise (1989), pp.101–116. Many of the references supporting William Thomson, including that from William Hopkins, are reproduced in Thompson (1910), v.1, pp.167–182.

James Thomson died quite soon afterwards, in a cholera epidemic of 1849, and William tried hard but unsuccessfully to persuade his friend G.G. Stokes (1st, 1841) to become his father's successor. On the relative merits of Stokes and a rival candidate, Hugh Blackburn, Hopkins wrote to Thomson that:

> if you determine to recognize the *scientific principle* in your election, and to elect a man who is sure hereafter to dignify his position by the highest scientific distinction, Stokes is *unquestionably your man*. If on the contrary you should think it right to recognize the primary importance of choosing one who has received his early education in your own institutions, you may well rejoice in such a candidate as Blackburn.[468]

Hugh Blackburn (5th, 1845) had studied at Glasgow before proceeding to Cambridge, where he was a classmate of William Thomson. Both Hugh Blackburn and his older brother Colin (8th, 1835), who became a judge, had been tutored by Hopkins. After Stokes' withdrawal because of his religious scruples, Hugh Blackburn was appointed, and his long tenure of 1849–79 was worthy but undistinguished.[469] Though a capable university administrator, he is now best known as the husband of the artist and book-illustrator Jemima (née Wedderburn), whose sketchbook diaries include several delightful cameos of Thomson, Maxwell, Helmholtz and others. During 1871–74, Hugh Blackburn was assisted, as lecturer, by a far abler mathematician, Thomas Muir. Muir had been a Glasgow student, then briefly a tutor in mathematics at St Andrews University, and had visited Berlin and Göttingen for further study.[470]

In due course, Blackburn was succeeded by William Jack (4th, 1859), like his predecessor a Glasgow graduate who went on to Cambridge. Previously the Professor of Natural Philosophy at Owen's College, Manchester during

---

468 Wilson (1990), v.1, p.59 n5.

469 He published just a single paper, on astronomy and at Thomson's invitation, in the *Cambridge and Dublin Mathematical Journal*. He also contributed to a section of Gregory & Walton (1845) on differential geometry, edited a reissue in 1854 of G.B. Airy's *Treatise on Trigonometry*, and collaborated with William Thomson in preparing a finely printed 1871 edition of Isaac Newton's *Principia*.

470 Jemima Wedderburn's autobiographical memoirs and many of her watercolour sketches are in Blackburn (1988). Thomas Muir was head of mathematics and science at Glasgow High School during 1874–92; and was then recruited by Cecil Rhodes as superintendent-general of education at Cape Colony, South Africa. He did fundamental mathematical work on the theory of determinants, and wrote a five-volume history of the subject. He received a knighthood in 1915 for his services to science. See Crilly (2004d).

1866–70, Jack held the Glasgow chair from 1879 until 1909. Between these appointments, he edited the *Glasgow Herald* during 1870–76, perhaps the only mathematics professor to edit a major newspaper.

An exact contemporary of Jack at Cambridge was Alexander S. Herschel (20th, 1859), who from 1866 to 1871 was also in Glasgow, as lecturer in natural philosophy and professor of mechanical and experimental physics at Anderson's Institution.[471] Unlike the ancient Scottish universities, the primarily technological "Andersonian" appointed few Cambridge graduates to its staff, Herschel being perhaps the first.

At St Andrews University, another of Thomson's friends and classmates, the German-born W.F.L. Fischer (4th, 1845), was appointed to the Chair of Natural Philosophy in 1847. And, as already described, in 1858–59 John Couch Adams (1st, 1843) briefly held the Mathematics Chair before returning to Cambridge to succeed Peacock as the Lowndean Professor. On Adams' departure in 1859, Fischer transferred to the St Andrews Mathematics Chair and held that post until 1877, but with no great distinction.[472]

At Aberdeen, the former Peterhouse fellow Frederick Fuller (4th, 1842) was Professor of Mathematics at King's College from 1851 to 1860, and then at the amalgamated University until 1878. Several of his best students went on to take the Cambridge Tripos with distinction. The Professor of Natural Philosophy at King's College from 1845 to 1860 was the same David Thomson who, during 1840–45, had lectured on natural philosophy at Glasgow University. Also briefly at Aberdeen was James Clerk Maxwell (2nd, 1854), appointed to the Chair of Natural Philosophy at Marischal College in 1856 (when Arthur Cayley was among the unsuccessful applicants). But Maxwell had to leave this post in 1860 when Marischal and King's Colleges joined forces—despite having married, in 1858, the daughter of the Principal of Marischal College. As David Thomson was the senior professor, and had become Sub-Principal of King's College, it was he who succeeded to the amalgamated chair. Later, George Pirie (5th equal, 1866) replaced Fuller as Professor of Mathematics at Aberdeen, from 1878 to 1904; and Charles Niven (1st, 1867) was Aberdeen's Professor of Natural Philosophy from 1880 to 1922.

---

[471] Butt (1996).

[472] W. Thomson, Fischer, and Blackburn had studied together with Hopkins, all three attending his summer reading party at Cromer on the Norfolk coast in 1844. Unusually, before going to Cambridge, Fischer had studied in both Berlin and Paris, where he took classes by such luminaries as Dirichlet, Poisson and Liouville: see Smith & Wise (1989), pp.79, 351. Known as "Franz" to his Cambridge friends, Fischer is later referred to as "William" rather than "Wilhelm", and his children adopted the surname "Fisher".

At Marischal College, Maxwell's duties resembled school-teaching more than lecturing, and his suitability for such activity was questionable. In 1857, he wrote to his friend, C.J. Munro, that he had a "small class with a bad name for stupidity. . . . So I have got into regular ways, and have every man *viva voce*'d once a week, and the whole class examined in writing on Tuesdays, and roundly and sharply abused on Wednesday morning; and lots of exercises which I find it advantageous to brew myself overnight."[473]

Maxwell failed to gain the Edinburgh Chair vacated by J.D. Forbes on becoming Principal of the United College of St Andrews University; but he was soon appointed to the Chair of Natural Philosophy at King's College, London, as already mentioned. After a period of private study at his country seat of Glenlair, in 1871 Maxwell was persuaded back to Cambridge as Cavendish Professor of Experimental Physics and first head of the new Cavendish Laboratory (a post that William Thomson had earlier been offered and refused); but Maxwell was to live for only eight more years.

The candidate who defeated Maxwell for the Edinburgh Natural Philosophy Chair was has friend Peter Guthrie Tait (1st, 1852), who went on to hold it for more than forty years. Previously, during 1854–59, he held the Mathematics Chair at Queen's College, Belfast. In sometimes uneasy collaborations with William Thomson, Tait did much first-rate research, both theoretical and experimental. Philip Kelland was the first Cambridge wrangler to hold a Scottish chair, as Professor of Mathematics in Edinburgh during 1838–79. After Kelland's death, this chair was held during 1879–1911 by George Chrystal (2nd, 1875), who also briefly held the St Andrews Mathematics Chair in 1877–79.

The extent to which Cambridge graduates then dominated Scottish as well as English academic appointments is clear: see Table C overleaf. Less clear, however, is the fact that many of the above were Scots who had first studied at a Scottish university before going on to Cambridge: the only exceptions are Kelland, Fischer, Fuller and Adams. The advantages of proceeding to Cambridge for more intensive study of mathematics were by then well recognised; but these men brought with them other attributes associated with the Scottish universities. In particular, they had received a broader, more philosophical education that encouraged scientific speculation and debate: for some, this was to prove an important complement to the rigorous training for the Mathematical Tripos.

J.D. Forbes was a key figure among Scottish reformers: he felt that the general, broadly based Scottish degree was in much need of modernisation,

---

473 Campbell & Garnett (1884), p.207; Harman (1990–2002).

Table C. Professors of Mathematics and Natural Philosophy at the four Scottish Universities during 1846–1900.

Mathematics:
St Andrews: Thomas Duncan (1820–58), J.C. Adams (1858–9), W.L.F. Fischer (1859–77), G. Chrystal (1877–79), Peter R. Scott-Lang (1879–1921)
Aberdeen: John Tulloch (1811–51 King's Coll.), F. Fuller (1851–60 King's Coll.; 1860–78), G. Pirie (1878–1904)
Edinburgh: P. Kelland (1838–79), G. Chrystal (1879–1911)
Glasgow: J. Thomson (1832–49), H. Blackburn (1849–79), W. Jack (1879–1909)

Natural Philosophy:
St Andrews: Adam Anderson (1837–46) W.F.L. Fischer (1847–59), William Swan (1859–80), Arthur Stanley Butler (1880–1922) [Also, as Principal of United Colleges of St Salvator & St Leonard, D. Brewster (1838–59), J.D. Forbes (1859–68)]
Aberdeen: D. Thomson (1845–60 King's Coll.; 1860–80), David Gray (1845–55 Marischal Coll.), J.C. Maxwell (1856–60 Marischal Coll.), C. Niven (1880–1922)
Edinburgh: J.D. Forbes (1832–59), P.G. Tait (1860–1901) [Also, as Principal, D. Brewster (1859–68)]
Glasgow: W. Thomson (1846–99) [then Chancellor (1904–07)], Andrew Gray (1899–1923)

Those underlined did *not* study the Cambridge Mathematical Tripos. Full names are given only for those not previously mentioned.

preferably along the lines of Whewell's vision of a "Liberal Education". Though he never enrolled as a student at Cambridge, in his youth he sought Whewell's advice on how best to study mathematics, and he made several visits to Cambridge, when he attended lectures. (Forbes was an Edinburgh graduate, who had the able William Wallace to advise him about mathematics. His consulting Whewell reveals more about the socio-political stratum to which the two belonged than about any deficiencies of Wallace.)

With the support of Philip Kelland and some other professors (most notably John Stuart Blackie and James Lorimer), Forbes brought about changes in Edinburgh that still managed to retain some of the better features of the Scottish degree.[474] Though an effective and popular teacher, Kelland did not live up to his early reputation as a brilliant researcher or, at least, to the hyperbole of his supporters for the Edinburgh chair.[475]

---

[474] Davie (1961); Morrell (1997); Anderson (1983).

[475] The suppliers of testimonials for Kelland are listed in Chapter 5, p.101 footnote. One supporter, J.J. Sylvester, described him as "the man most likely, in this country at least, to widen the boundaries of our physical knowledge, and lead the van of science": Forbes (1838).

Scottish educational reforms at both University and school level were continued by Kelland's able successor, George Chrystal (2nd equal, 1875), who had studied at Aberdeen and Cambridge. As well as taking the Mathematical Tripos, Chrystal studied experimental physics with Maxwell, and undertook electrical experiments under his direction. Chrystal played a large part in setting up the Scottish Leaving Certificate examinations in the schools. Another much involved in school education was John E.A. Steggall (2nd, 1878), who became the first professor of Mathematics and Natural Philosophy at University College, Dundee, after a time at Owen's College, Manchester.[476]

Although appreciating the advantages of having studied at Cambridge, Chrystal was not the only Scot to be critical of the system, or lack of it, that he encountered there:

> When I went to the University of Cambridge, I found that the course there for the ordinary degree in Arts was greatly inferior in quality to the Scottish one. On the other hand, the courses in honours were on a very much higher standard, although they suffered greatly from the chaotic organisation of the English Universities. . . . I might liken the difference between the English and Scottish University courses at that time to the difference that then existed between their national styles of cookery. The Scottish cuisine was characterised by lightness and variety, the English cuisine was noted for plenty and excellence of material, but lacked variety, and the defective preparation of its dishes often left them heavy and indigestible. I have frequently been tempted to think that the three years I spent as an undergraduate at Cambridge were wasted years of my life, if they were to be valued merely by the amount of new knowledge acquired, no doubt they were largely wasted, but, on the other hand, they were of great advantage to me in other respects. I made the acquaintance of a large number of the ablest young men of my generation. . . .[477]

Ireland and Overseas

During the mid-nineteenth century, the Irish university colleges experienced a smaller influx of Cambridge graduates than was the case in Scotland, and they appointed more purely home-grown talent. In part, this was attributable

[476] Mason (2004).

[477] Chrystal (1892).

to the strong local tradition in mathematics inaugurated by Bartholomew Lloyd (1772–1837) at Trinity College, Dublin. Lloyd, who had himself studied at the college, held the chairs of both mathematics and natural philosophy, and he served as its Provost from 1831 until his death. Illustrious graduates included William Rowan Hamilton, George Salmon, James MacCullagh and John Casey, whose achievements in mathematics and physics stand comparison with the best of their Cambridge-trained contemporaries.[478] Rather later, the mathematical physicist George Francis FitzGerald (1851–1901) also studied at Trinity College, Dublin and went on to hold appointments there. His work on electricity and magnetism built on Maxwell's, and he made an early contribution to relativity theory (commemorated in the *Fitzgerald-Lorenz contraction*).

Some Irishmen, including G.G. Stokes, M. O'Brien, R. Murphy and F.Y. Edgeworth, were based at English universities and colleges, as already noted. Another was Henry Smith (1826–83), born in Dublin but educated in England at Rugby school and Oxford, who became Oxford's Savilian Professor of Geometry, and published research on geometry, number theory and matrix theory. And Belfast-born Osborne Reynolds (1842–1912), who studied at Cambridge (7th, 1867), spent his career as professor of engineering at Owen's College, Manchester, where he made important contributions to fluid mechanics.

Later, several more Irish mathematicians followed the Scottish pattern, first studying at Irish colleges and then at Cambridge, and often returning to teach in Ireland. For instance, the mathematical physicist Joseph Larmor (1857–1942) studied at both Trinity College, Dublin and Cambridge (1st, 1880), and went on to hold professorships at Queen's College, Galway and then at Cambridge. He was George Gabriel Stokes' successor in the Lucasian chair—one Irishman succeeding another. William McFadden Orr (1866–1934) was educated at Queen's College, Belfast and then at Cambridge (1st, 1888): he then taught at the Royal College of Science in Dublin (later University College, Dublin). Influenced by Lord Rayleigh and William Thomson, he performed valuable research on the stability of fluid flows: in this field, the *Orr-Sommerfeld equation* bears his name.

Among *non*-Irish Cambridge wranglers who held academic posts in Ireland, a notable early appointee was John Brinkley, the senior wrangler of 1788. After a brief apprenticeship at Greenwich Observatory, and aged only twenty-four, he became Andrews Professor of Natural Philosophy at Trinity College, Dublin, and soon afterwards Royal Astronomer of Ireland.

[478] Some of their work is discussed in Chapter 12 below.

In our period, William Parkinson Wilson (1st, 1847) spent five years as Professor of Mathematics at Queen's College, Belfast (1849–54) before taking up a similar post at Melbourne, Australia (1854–74), where he too was much involved with astronomy. Peter Guthrie Tait succeeded Wilson as Professor of Mathematics at Queen's College, Belfast, and remained there until his appointment to the chair of Natural Philosophy at Edinburgh in 1860. Tait's successor at Queen's was the ill-starred George Slesser (1st, 1858), who showed great promise but died just two years after his appointment, aged twenty-eight. Like Tait, Slesser was a Scot, but unlike Tait his background was far from privileged: he was the son of a crofter from Buchan in Aberdeenshire.

An interesting appointment was that of the largely self-educated Englishman George Boole, of Lincoln. He was awarded the chair of mathematics at the new Queen's College, Cork in 1849, and he held the post until his death in 1864. Boole's revolutionary work on algebras (including what is now called *Boolean algebra*), differential operators, and mathematical logic were to prove of lasting significance. Another Scot, Charles Niven (1st, 1867), held the mathematics chair at Cork during 1867–80, before returning to his home ground of Aberdeen.

As well as J.J. Sylvester, whose two sojourns in the United States were mentioned above, some others went overseas to university and college posts. The American-born Morris Birkbeck Pell (1st, 1849) and William Scott (3rd, 1848) were in Sydney, Australia, and W.P. Wilson was in Melbourne. So too was James Wilberforce Stephen (4th, 1844), who became a judge in Victoria. And J.J. Sylvester, then unemployed, had considered applying for the Melbourne professorship in 1875, following Wilson's early death: but Arthur Cayley seems to have advised against it.[479]

William Archer Porter (3rd, 1849) first practised law at Lincoln's Inn, then went to India, where he was a college principal and tutor to a maharaja. Also in India were Charles Baron Clarke (3rd equal, 1856), who first taught at Presidency College, Calcutta and then became Inspector of Schools in East Bengal; and the administrator Henry Maine (1st classic, 1844), who, among other appointments, was Vice-Chancellor of Calcutta University. Their stories are told more fully in the next Chapter.

John Bradford Cherriman (6th, 1845) went to University College Toronto, in Canada, as Professor of Natural Philosophy. And Richard Potter (6th, 1838) also spent a year there, on leave from University College, London. Duncan F. Gregory was another who might have gone there, in 1841, but had to decline because of the illness that brought his early death. John Bainbridge Smith

[479] See Parshall (2006), p.223.

(24th SO, 1844) was Professor of Mathematics and Vice-Principal of King's College, Nova Scotia during 1847–54, before returning to England as a clergyman. In 1847, W.F.L. Fischer was offered the post of Astronomer at the Cape Town Observatory in southern Africa (a post previously held by John Herschel), but he accepted the rival offer of a St Andrews chair instead.[480] Two who did go to the Cape were Charles Abercrombie Smith (2nd, 1858), who served two periods as Vice-Chancellor of Cape University (now the University of Cape Town); and Edward James Stone (5th, 1859) who, after ten years as Chief Assistant at the Royal Greenwich Observatory, served as Astronomer Royal of the Cape of Good Hope during 1870–79. Stone then returned to England to become the Radcliffe Observer at Oxford University.

Somewhat later, more wranglers worked in universities overseas. The most illustrious was Horace Lamb (2nd, 1872), the first Professor of Mathematics at the University of Adelaide, Australia during 1875–85, who then joined Owen's College, Manchester. Others include A.A. Bodkin (23rd equal, 1869), Professor of Mathematics at the Diocesan College, Rondebosch, South Africa; H.M. Andrew (27th, 1872), Professor of Natural Philosophy, and E.J. Nanson (2nd, 1873), Professor of Mathematics, both at the University of Melbourne, Australia; Thomas Gurney (3rd equal, 1873), M.B. Pell's successor as Professor of Mathematics at the University of Sydney, Australia; and J. Cox (9th, 1874), Professor of Physics at Montreal University, Canada.[481]

[480] Ellis (1865); Knight (1903), pp.160–162.

[481] *Cambridge University Calendar* 1909–10, pp. 270–275.

10.

Wranglers Abroad: Churchmen and Educators in the Colonies

Australia: C. Perry, J.W. Stephen, W.P. Wilson, A. Barry, M.B. Pell, W. Scott, J. Cockle

Six of our top wranglers served the Church, education and the law in Australia. And a seventh, James Cockle, though a lowly wrangler, was an able mathematician and jurist. The Bishop of Melbourne during 1847–76 was Charles Perry (1st, 1828), senior wrangler in the year after De Morgan and Hopkins. Perry coincided in Melbourne with William Parkinson Wilson (1st, 1847), when the latter was professor of Mathematics at Melbourne University during 1854–74; and also with the lawyer James Wilberforce Stephen (4th, 1844). Stephen became a member of the Victoria Legislative Assembly and then a Judge of the Supreme Court. He was active in promoting education in Victoria; he also served as Chancellor of the Anglican Diocese of Melbourne, and was a member of the Council of the University of Melbourne.[482]

Alfred Barry (4th, 1848) became Bishop of Sydney in 1884, quite late in his career at the age of fifty-eight. He was appointed to the Senate of the University, where two other wranglers and contemporaries had long worked. But Morris Birkbeck Pell (1st, 1849) had died before Barry's arrival, and William Scott (3rd, 1848) had retired. The three had known one another as students, and Scott and Barry surely met again, thirty-six years later on the other side of the world.

As well as being an able mathematician, Alfred Barry had obtained a first class in the Classical Tripos. He then trained for the law, and was admitted to the Inner Temple in 1846; but he soon turned to teaching at a Scottish boarding school, Trinity College, Glenalmond. After ordination as a priest in 1853, he was successively headmaster of Leeds Grammar School (1854–62),

[482] See also Chapter 7, pp.154, 157, 158, and Chisholm (c.1958).

Principal of Cheltenham College (1862–68), and a reforming Principal of King's College in London (1868–83).

From 1860, he maintained a steady stream of publications: sermons, lectures, commentaries on books of the Bible, works on Church affairs and other religious tracts. From 1871 to 1883, he held a succession of prestigious Church appointments: Canon of Worcester (1871–81), Chaplain-in-Ordinary and then Chaplain to Queen Victoria (1875–83), and Canon of Westminster (1881–83). But a biographer recounts that "his intense and notorious desire to secure a see counted against him, and he was not appointed to an English bishopric."[483]

In 1876 he was offered, and refused, the see of Calcutta. Then, at last, in 1884 he was appointed Bishop of Sydney, Metropolitan of New South Wales and Primate of Australia, posts that he held for just five years, until 1889. There, he was active in improving old and founding new Church secondary schools, and in promoting the interests of the diocesan theological college, which he wished to be more closely associated with the University of Sydney. But he did not settle well into his new life: he was not greatly popular, and he was criticised for making long visits back to England. No one was surprised when he resigned.[484]

The American-born Morris Birkbeck Pell emigrated to Australia in 1852 to become the first Professor of Mathematics and Natural Philosophy at the newly founded Sydney University. In 1856, William Scott joined Pell in Sydney. For about six years, Scott served as the first Director of the Sydney Observatory; then, during 1865–82, he was Warden of St Paul's College at Sydney University. Meanwhile, the first Professor of Mathematics at the new Melbourne University was William Parkinson Wilson.

The experiences of these early university teachers at Sydney and Melbourne did not much resemble those of their counterparts in long-established British universities. Sydney University was founded in 1850 and Melbourne just three years later. Both cities were experiencing very rapid expansion from small beginnings. Sydney, in the Colony of New South Wales, grew from the first British penal settlement founded at Port Jackson in 1788, some eighteen years after James Cook first sailed into Botany Bay. By 1821, the population of Sydney was about 30,000 (three-quarters of them transported convicts); in 1861 it had risen to just under 100,000; and it underwent a further fivefold increase to nearly half a million by 1901. Similarly,

[483] Pearce (2004).

[484] Returning to England at the age of 63, he went on to hold several further ecclesiastical appointments: Assistant Bishop of Rochester (1889–91) and of London (1896), Canon of Windsor (1891–1910), Rector of St James, Piccadilly in London (1895–1900). He died on 1 April 1910.

Melbourne, in Victoria, had grown from just a few huts in 1835 to a population of 6000 in 1840, and 496,000 in 1901.

The founding of the two universities owed more to growing civic pride and ambition than to any genuine need for higher education. The demand was for strong arms, and skills in farming, carpentry, building and mining, rather than for highly trained minds. Most lawyers, accountants, churchmen and other professionals were British-trained immigrants. Protests were made in 1849 over the British Government's plan to resume transportation of criminals to the Sydney area. And the discovery of gold near Sydney in 1851 led to further boatloads of fortune-hunting immigrants. The first Education Act of 1867 ensured the introduction to Sydney of compulsory *primary* education; and a further act of 1880 made education compulsory between the ages of seven and fourteen years. A similar act was passed in Victoria in 1872 following its promotion by J.W. Stephen, then the colony's Attorney General and Minister for Public Instruction.

The University of Sydney

The University of Sydney replaced an earlier, privately owned foundation, the Sydney College, and at first occupied the earlier college's premises.[485] The University of Sydney was planned as a non-sectarian and secular university along the lines of the new London University. Resisting objections to a "Godless College" by Anglicans, Roman Catholics and Presbyterians alike, the New South Wales Legislative Assembly ratified the Act of Incorporation in 1850, and a remarkably grand and imposing set of buildings was commissioned from the architect Edmund Blacket. The University opened its doors to its first students in 1852, though the buildings were not completed until 1860.[486]

But the University of Sydney was not the only centre of intellectual activity. As early as 1827, the Australian Museum in Sydney had been founded. An early "Australian Philosophical Society" was revived in 1856 as the Philosophical Society of New South Wales; and in 1867 this became the Royal Society of New South Wales. The Museum of Natural History held popular meetings on botany and mineralogy, and amateur scientists and collectors among the gentry hosted fashionable soirées. As Sydney grew, so did its civic and religious buildings. The Roman Catholic St Mary's Cathedral and the Anglican St Andrew's Cathedral were built. The latter, founded in 1819, was

---

[485] Later, these buildings became the site of the Sydney Grammar School. A rival "Australian College" staffed with "professors" had been founded by a Dr Lang around 1830 but it did not survive for long.

[486] Barff (1902).

eventually completed in 1868, some sixteen years before Alfred Barry succeeded to the bishopric.

The first Principal of the University was John Woolley, a London and Oxford-educated classical scholar and clergyman, who successfully maintained the non-sectarian nature of the University teaching. But he and his fellow professors supported moves for the creation of residential colleges for the main religious groups, where both tutorial assistance and systematic religious instruction were to be available. The first of these colleges were St Paul's (Church of England, 1854), St John's (Roman Catholic, 1857) and St Andrew's (Presbyterian, 1867).[487] Though the early model was the non-sectarian University College, London, the residential colleges added a social dimension much closer to that of Oxford and Cambridge. The first Provost (or Chancellor), elected by the Senate in 1851, was Edward Hamilton, a former Fellow of Trinity College, Cambridge, and fifth wrangler in 1832.[488] But Hamilton lived at some distance from Sydney and did not participate very actively: in 1854 he resigned in favour of the Vice-Provost, Sir Charles Nicholson, an Edinburgh medical graduate.

Following the Act of Incorporation, an eminent committee was appointed in England to select the staff of the new university: it comprised the two Cambridge-trained scientists George Biddell Airy and Sir John Herschel, Henry Malden (another Cambridge graduate and Professor of Greek at University College, London), and Henry Denison (a classicist of All Souls College, Oxford). They were instructed that "the Classical and Mathematical Professors should bring with them the high Academical distinction of one of the Universities of Oxford and Cambridge . . . [confined to] first-class men at either University in Classics, and the first ten wranglers in Mathematics at . . . Cambridge." Also, in Experimental Philosophy, the model should be the "course adopted by the Plumian Professor at Cambridge" but including subjects associated with other chairs, such as the Jacksonian Chair at Cambridge; whereas the Chemistry course should resemble that at Edinburgh, or at King's College or University College, London.[489] Presumably, Hamilton's familiarity with the Cambridge scene of twenty years before had influenced these criteria. A further Cambridge connection was the later establishment of a post of "Esquire Bedell", the same office as that held in Cambridge by William Hopkins.

[487] A non-sectarian Women's College was added in 1892, a long-planned Wesley (Methodist) College opened in 1910, and the Sancta Sophia College (for Roman Catholic women) followed in 1929.

[488] It is quite likely that he, too, had been taught by William Hopkins.

[489] Barff (1902), pp.16, 17.

The professors and students were required to wear gowns and mortar boards. When the novelist Anthony Trollope visited Sydney University in 1871, he deplored the unsuitability for the climate of this academic dress, as the students "cantered out to lectures in surroundings that only the occasional gum or fig tree differentiated from a fragment of Oxford or Cambridge."[490]

The first staff consisted of just three professors and a registrar, and the first twenty-four students were admitted in 1852. The Principal, John Woolley, was also Professor of Classics; the other two were Morris Pell, Professor of Mathematics and Natural Philosophy, and John Smith, Professor of Chemistry and Experimental Physics. The staff were rather well paid: Woolley received £800 p.a. and the other two professors £400 p.a. each.[491] The latter sum was considerably more than G.G. Stokes first received as Cambridge's Lucasian professor; but even Woolley's salary fell far short of the total annual earnings of William Hopkins.

The three-year M.A. degree consisted of Greek, Latin, Mathematics and Science: early plans for degrees in law and medicine were not realised until the 1880s. A planned chair in natural history was also postponed, much to the disappointment of the English biologist T.H. Huxley, who had been an enthusiastic visitor. After thirty years of existence, student numbers at Sydney University remained as low as 100. Only after 1880 did rapid expansion take place, underpinned by better school education and financed by an increase in the Government grant and by an astonishingly large bequest of £276,000 from John H. Challis, a Sydney merchant (apparently unconnected with the Cambridge professor James Challis), which allowed the appointment of further professors in a range of subjects.

The Principal, John Woolley (1816–66) was born in Petersfield, Hampshire, and was an outstanding student at London University and then at Exeter College, Oxford, where he obtained a B.A. with First-Class Honours in Classics in 1836.[492] He published an *Introduction to Logic* in 1840, and a volume of sermons in 1847. As well as teaching Classics and Logic at Sydney University, he gave free lectures at the Sydney School of Arts, and he supported the Sydney Grammar School. A volume of his lectures was published in 1862. In 1865 he revisited England for a vacation; but, while returning to Australia, he

[490] Birch & Macmillan (1962), p.103.

[491] Barff (1902), p.4.

[492] Before going to Sydney, he was successively a fellow of University College, Oxford, then headmaster of grammar schools in Hereford, Rossall in Lancashire, and Norwich. In 1842, he married Margaret Turner and they had six children. (He is not the same J. Woolley who was 3rd wrangler in Cambridge in 1840.)

perished with many other passengers when the steamship *London* sank in the Bay of Biscay on 11 January 1866.

At the formal opening ceremony and first matriculation on 11 October 1852, the Vice-Provost, Sir Charles Nicholson, and Principal Woolley delivered what were described as "very eloquent addresses".[493] Woolley's address began with the founding of Oxford University (allegedly) by Alfred the Great, and went on at length to extol the merits of studying Latin, Greek and Mathematics. His extravagant rhetoric is evident, too, in a later 1860 address to the Sydney School of Arts, where he lambasts the lack of education in the colonial society which he has joined. He urges the citizens to:

> force our governors to break through the meshes of faction and bigotry, and help, by act as well as word, to purge that putrid mass of ignorance and insensibility, which decimates our population, whilst it multiplies our gaols, makes the streets of our city a field of blood, from which the festering corpses of our strongest and fairest cry to God against us, our settlements in the bush too often more brutal and savage than those of the dispossessed aborigines. And why are we so little earnest in the cause of education? Because we are not thoroughly convinced of its practical utility; we do not see what good our children will get from it, how it will help them on in the world, or promote their success in a life where self-reliance and readiness of resource seem of more value than all the wisdom of Solomon.[494]

Although Woolley highlights a problem, it must be doubted that an effective solution was offered by his ideal of liberal non-vocational education, with the Classical languages, mathematics, natural philosophy and experimental science as its core. Nevertheless, he "took a prominent part in the social life of the colony, on which he exerted a great and most beneficial influence."[495]

John Smith (1821–85) was a more practical, down-to-earth sort, the son of a blacksmith from the village of Peterculter in Aberdeenshire, Scotland. In 1843, he graduated M.A. with distinction from Aberdeen University, and he was awarded the M.D. medical degree in the following year. He lectured in chemistry at Marischal College, Aberdeen before taking up his Sydney appointment in 1852. He remained in post until 1881, and played a major role in the development of science in Australia. On his arrival in Sydney, he was immediately enlisted to analyse the quality of Sydney's dubious water supply.

---

[493] As these are reproduced in Barff (1902) pp.20–41, one can judge them for oneself: the first twenty-four students must surely have found them interminable and largely incomprehensible.

[494] Barff (1902), p.78.

[495] Barff (1902), p.76.

Some of the well water was so bad that he found it "difficult to determine whether it is an animal, vegetable or mineral substance."[496] His criticisms eventually led to the establishment of the Sydney Water Board in 1859, of which body he later became chairman.

Smith was a keen photographer, and was among the first in Australia to take wet-plate photographs. In 1858, he took part in Australia's first ever photographic exhibition. A cache of more than 300 of his negatives, dating from the early 1850s, was discovered in a cellar of Sydney University in 1955. These include many historic images, including one of the still-unfinished University buildings (circa 1858), showing the first three professors.

Figure 13. Sydney University under construction, circa 1859, with Professors Smith (left), Pell (centre) and Woolley (right). Photograph by Professor John Smith. (P209_31: courtesy of University of Sydney Archives.)

[496] Birch & Macmillan (1962), p.93.

Smith joined the Board of National Education in 1853, and served nine times as its president. He also served on the University Senate during 1861–85. In the late 1870s, he was one of only two members of the latter body to support a defeated proposal to admit women; but women were admitted soon after, in 1881.[497]

Morris Birkbeck Pell (1827–79) was born in Albion, New York, the son of Gilbert Titus Pell and Elizabeth Birkbeck, the daughter of Morris Birkbeck, a noted Quaker who settled in Illinois.[498] His early years were spent in New York, Mexico and England, before entering Cambridge University and graduating as senior wrangler in 1849. For the two years between graduating and going to Sydney, he was a fellow of St John's College. At that time, he published a book of *Geometrical Illustrations of the Differential Calculus* (1850) for use by students. He held the post of Professor of Mathematics and Natural Philosophy at Sydney until ill health forced his retirement in 1877, and he died in Sydney two years later, aged fifty-two. He became a barrister of the Supreme Court of New South Wales in 1863, and an actuary of the Australian Mutual Provident Society. Like Smith, he was active in improving the water supply of Sydney, chairing a Water and Sewerage Commission and serving on a Floods Prevention Commission. For a time, he was a trustee of the Sydney Grammar School. As professor, he was succeeded by another wrangler, Thomas Gurney (3rd equal, 1873) who, like Pell, was not an active researcher.[499]

The appointment of William Scott (1825–88) in 1856 as Professor of Astronomy might seem strange, in view of the small size of the University. But this was not a teaching appointment: Scott, the third wrangler of 1848, was recruited as first Director of the newly founded Sydney Observatory, on the recommendation of George Airy, the Astronomer Royal at Greenwich.[500]

The first Australian observatory had been founded in 1822 at Parramatta, built and equipped at the personal expense of the Governor, Sir Thomas Brisbane. Its situation in the southern hemisphere was important to

[497] He was also a founder and director of the Australian Mutual Provident Society, formed in 1864; and he held office in the Philosophical Society of New South Wales (from 1867 the Royal Society of New South Wales). He became a member of the New South Wales Legislative Council in 1873 and received various honours, including an honorary LL.D. (1876) from the University of Aberdeen. See Chisholm (c.1958) v.8, pp.152, 153.

[498] He was more distantly related to George Birkbeck, the founder in 1823 of the Mechanics Institute in London, after whom Birkbeck College, London is named.

[499] According to Chisholm (c.1958), v.7, p.50, Pell also wrote works on railways, the construction of dams, and insurance. Gurney was not senior wrangler, as stated by Moyal (1986), p.165.

[500] There is some doubt as to whether he bore the title of professor as recorded in Venn & Venn (1940): Barff (1902), p.52 refers to him only as "Rev. W. Scott M.A."

Figure 14. Photograph of Morris Birbeck Pell by John Smith, 1860s. (G3_224_1398: courtesy of University of Sydney Archives.)

astronomy, and some notable observations were made. But it was allowed to fall into dilapidation and ceased operating in 1846. In 1856, it was decided to establish a replacement in Sydney, and the new building was completed two years later. Scott supervised its erection, and acquired meteorological instruments for new weather stations in the vicinity. Some of the equipment from Parramatta was rescued, but it was in such poor state that Scott at first had to use a sextant to record the path of a comet. A new equatorial telescope with 71/4-inch aperture was eventually acquired and set up in 1861, just in time for Scott to observe another comet.[501]

[501] Moyal (1986), pp.132–134.

This 1861 comet was discovered not by Scott but by an amateur enthusiast, John Tebbutt (1834–1916) of Windsor, N.S.W., using only a marine telescope. Scott recognised Tebbutt's talent, but advised him to leave Windsor for a better-equipped observatory:

> With your enthusiastic love of Astronomy, mathematical ability and industry you might become one of the distinguished Astronomers of the age, in fact Australia's first Astronomer; but if you remain where you are without instruments you may amuse yourself by rough observations and calculations, but you cannot add one particle to the real treasures of science.[502]

However, Tebbutt chose to remain in Windsor, building a small private observatory and improving his equipment, where, contrary to Scott's gloomy predictions, he made some notable observations.[503]

Scott resigned his directorship to become headmaster of the Collegiate School in 1864, then Warden of the Anglican St Paul's College at the University, a post that he held from 1865 until 1882. He had been ordained a priest in 1850, and the St Paul's post would have involved religious instruction and pastoral work with its students; but he probably tutored them in mathematics and natural philosophy as well. He wrote an *Elementary Treatise on Plane Co-Ordinate Geometry with its Application to Curves of the Second Order*. He died in Australia in 1888.[504]

Another native-born Australian, Henry Chamberlain Russell (1836–1907), was one of Sydney University's first graduates, and from 1858 he worked with Scott as a computer at the new observatory. Later, in 1869, he became its director and government astronomer, following the death of Scott's successor, George Roberts Smalley.[505] G.R. Smalley (24th, 1845) had taught mathematics at King's College School in London for seven years. He then served for a year as lecturer in Natural Philosophy at King's College, where James Clerk Maxwell

---

502 Moyal (1986), p.134, quoting Tebbutt Corresp., Mitchell Library, Sydney, 16 April 1860.

503 The most spectacular of these was his discovery in 1881 of a second great comet, which was named "Tebbutt's Comet". Tebbutt had helped Scott in calculating occultations of stars and eclipses; but he turned down the opportunity to succeed him as director of the Sydney Observatory. Tebbutt's services to astronomy were recognised in 1905 by the award of a medal from the Royal Astronomical Society. See Moyal (1986), pp.134, 135.

504 Confusingly, several other mathematical works were written by another author with the same name, William Scott (1800–54).

505 Russell was noted for his stellar and lunar photography, and was the first Sydney graduate to be elected a fellow of the Royal Society of London: Moyal (1986), p.136.

was professor. But his tenure as director of the Sydney observatory during 1864–69 was a brief one.

One who may well have met Pell, Smith and Scott in Sydney was the young William Stanley Jevons (1835–82), who later returned to England and became a distinguished political economist and logician. For five years, from the age of eighteen, the nonconformist Jevons was rather unhappily employed as an assayer at the Sydney Mint.

The University of Melbourne

Melbourne University benefited from a higher level of funding in its early years, and so grew more rapidly than Sydney University from a slightly later start. Just eighteen months after the founding of the state of Victoria itself, the University was established in 1853 with four professors. From fifteen students in 1855, there were two hundred sixty-three in 1879 and more than five hundred by 1900. As at Sydney, a system of denominational residential colleges gradually evolved.

William Parkinson Wilson was born in Peterborough, where he studied at the Cathedral School before entering St John's College, Cambridge in 1843. Just two years after graduating as senior wrangler, he was appointed Professor of Mathematics at Queen's College, Belfast; but in 1854 he left this post to become professor of Mathematics at the newly founded Melbourne University. He remained there until his death in 1874, aged only forty-eight. He was the author of *A Treatise on Dynamics* (1850), published in Cambridge.

Wilson is remembered more for his involvement with astronomy than with mathematics. In 1857, the Royal Society of London, the British Government and the Government of Victoria made plans for a great new telescope, and Wilson was actively involved in securing this for Melbourne. The new observatory was established in 1863, and Robert L.J. Ellery (1827–1908), who had gained some experience at the Royal Greenwich Observatory, was appointed as government astronomer. In 1869, the "Great Melbourne Telescope" was installed. Designed and mounted by the leading maker Thomas Grubb of Dublin, it was a huge 48-inch Cassegrain reflector, with a speculum metal mirror having a focal length of 160 feet.[506]

This expensive and ambitious venture was the nineteenth-century equivalent of the Hubble space telescope project of the late twentieth century. And, like the Hubble telescope, matters did not run smoothly. There were major transportation and installation difficulties of so large a piece of equipment.

---

506 Moyal (1986), p.137.

Worse, to protect the speculum during transit, its surface had been coated with a layer of shellac; but removing the shellac itself resulted in damage to the surface. As a result, the performance of the telescope never came up to expectations, although some useful observations were made.

Later, two more wranglers joined the staff of Melbourne University: Henry Martyn Andrew (27th, 1872) as Professor of Natural Philosophy in 1883–88, and Edward John Nanson (2nd, 1873) as Professor of Mathematics in 1875–1922. Like Wilson, Scott and Pell before them, neither published much, but it is understandable that these early Australian professors did not become distinguished researchers. Their main involvement was with the ongoing affairs of the rapidly changing society in which they were expected to play a prominent part. The infrastructure of science, education and public health owed much to their efforts. However, a truly gifted and motivated researcher could have made more of a mark: the stamp of a "high wrangler" was no guarantee of later eminence.[507]

Queensland

James Cockle (1819–95), though ranked only 33rd wrangler in 1842, went on to write around one hundred mathematical papers and to become President of the London Mathematical Society in 1886. His mathematical output therefore far outstripped that of all the other Australian-based wranglers of his time. He pursued a legal career in London until his appointment in 1863 as Chief Justice for Queensland, which had separated from New South Wales just a few years previously.

An able administrator, Cockle applied the law fairly, and skillfully redrafted and consolidated many statutes. For these services, he received a knighthood in 1869. While chairman of the trustees of Brisbane grammar school (1874–77), he endowed a mathematics prize; and he was president of the Queensland Philosophical Society during 1863–77. According to his biographers, "His impartiality and tolerance were influenced by his strong Christian princi-

[507] Moyal (1986), p.161 complains (a little unfairly, for they professed different subjects) that the appointment by Sydney University of John Smith rather than T.H. Huxley, was "a substitution of steadiness for genius which has frequently characterised Australian university life." But she rightly exempts the later University of Adelaide from these strictures: this "nourished two researchers of great distinction", the hydrodynamicist and mathematician Horace Lamb (2nd, 1872) and the physicist William Bragg (3rd, 1884).

Before attending Cambridge, H.M. Andrew had lived for a time in Australia. Before joining the University of Melbourne, he was headmaster of the Wesleyan College in Melbourne during 1875–82.

ples."[508] Cockle left Queensland on a year's paid leave in 1878; but, finding social and scientific life in London more agreeable, he resigned from his post.

His interests in mathematics encompassed topics in pure mathematics, and also hydrodynamics and the influence of magnetism on light. His appreciation of the history of science led him to publish several works on early Indian astronomy—a topic that links to our next section.

India: H. Cotterill, J.H. Pratt, C.B. Clarke, W.A. Porter, J.B. Phear

For much of the eighteenth century, the English Honourable East India Company was more concerned with trade than conquest, and many of the British in India adopted local dress and ways of life, with Indian mistresses or wives both Hindu and Muslim. Interest in the history and the rich and ancient culture of India was encouraged by the enlightened Governor-General Warren Hastings and the judge Sir William Jones. But, towards the end of the century, growing British power led to changing attitudes. The appointment in 1786 of Lord Cornwallis as Hastings' successor resulted in increasing discrimination against Anglo-Indian children of mixed race, who were debarred both from employment by the East India Company and from owning property. Expatriate society in India became increasingly English in character, and ever less tolerant of those who adopted Indian lifestyles. Christian missionaries railed against the "paganism" and "idolatry" of Hindus, with little or no knowledge of their ancient traditions.[509]

In 1797, Richard Colley Wellesley (1760–1842), soon to become Marquess Wellesley, succeeded as Governor General and head of the Supreme Government of India. He systematically intensified the drive to military conquest of the independent Indian states. Also, as a visible symbol of British rule, he insisted on a prominent role for the Anglican church: all company servants and military officers were required to attend Sunday services.[510]

Yet many who served in India during the nineteenth century genuinely believed that they were benefiting the sub-continent as well as increasing

---

508 Corley & Crilly (2004).

509 See, for example, Dalrymple (2003; 2004).

510 According to Dalrymple (2003), p.54, "his Imperial policies would effectively bring into being the main superstructure of the Raj as it survived up to 1947; he also brought with him the arrogant and disdainful British racial attitudes that buttressed and sustained it."

British power and wealth. According to *The Cambridge Encyclopaedia of India, Pakistan, Bangladesh* . . . , for much of the nineteenth century British colonial rule in India

> was characterized . . . by optimism about the 'civilizing mission' supposedly undertaken on India's behalf. Technology, public works, education and law were confidently expected to produce a social and economic revolution which would make British rule both welcome and indispensible in India; many thought railways and trade would be sufficient in themselves. The idea of progress united diverse opinions, and allowed . . . celebrated and different members of the Indian government . . . to justify conquest and illiberal laws by the need to modernize backward peoples.[511]

The Cambridge graduate (but no mathematician), Thomas Babington Macaulay (1800–59), who later became Lord Macaulay, served on the newly formed Supreme Council of India during 1834–38. There, his main contribution was a major revision of the legal code. A strong advocate of the Anglicisation of Indian society, he wrote in his *Minute on Indian Education* (1835) that "We must . . . do our best to form a class who may be . . . Indian in blood and colour, but English in taste, in opinions, in morals and in intellect. To that class we may leave it to refine the vernacular dialects of the country. . . ." Several high Cambridge wranglers from our period played their different parts in this process of Anglification.

Henry Cotterill (1st, 1835) was a young man in a hurry to enter the Church. He was ordained deacon in his year of graduation and priest the following year. He chose to hold a fellowship at St John's for just a year, resigning to marry and to take up a post as chaplain at Madras, India.[512] At first, he assisted at the Presidency (the British Government headquarters at Fort St George). A new Bishop of Madras was installed in 1838, and Cotterill took charge of St Matthias' Church, Vepery, a district comprising several villages and including the General Hospital. Other than brief factual mentions of his existence there,

---

[511] Robinson (1989), p.116.

[512] His father was the Anglican rector of Blakeney in Norfolk: both he and Henry's grandfather had also attended St John's College. From the age of fifteen, Henry and his elder brother George were private pupils at Cambridge of J. Scholefield, later Regius Professor of Greek at Cambridge University. As well as becoming senior wrangler, Henry Cotterill was first Smith's Prizeman and ninth in the First Class of the Classical Tripos—one of the best ever overall performances [rivalled around this time only by C. Perry (1st, 1828) and equal 7th classic; W. Selwyn (6th, 1828) and 1st classic; and A. Barry (4th equal, 1848) and 7th classic]. Henry Cotterill married Anna Panther, daughter of a Jamaican estate owner, and they had four sons and two daughters. See Cazenove (1867).

little is recorded of Cotterill's life in India. But it is known that his health became adversely affected by the climate, and after eight years he returned to Britain.[513]

In 1847, he was appointed Vice-Principal of the new Brighton College in England, and in 1851 he succeeded as its Principal. But he soon left again for the Colonies, this time to Africa, as Bishop of Grahamstown, a post that he held from 1856 to 1871 (see the following section). His final post was as Episcopalian Bishop of Edinburgh, which he held from 1872 until his death in 1886.

After a few years as a fellow and private tutor at Gonville & Caius College, John Henry Pratt (1809–71), 3rd wrangler in 1833, was appointed in 1838 as a chaplain of the East India Company in Calcutta. He later became domestic chaplain to Daniel Wilson, the Bishop of Calcutta, an Oxford graduate of Evangelical persuasion. In 1850, Pratt was appointed Archdeacon of Calcutta.

Pratt, like Cotterill a former pupil of William Hopkins, is remarkable for having been able to combine his ecclesiastical duties with scientific work of a high level.[514] His *Mathematical Principles of Mechanical Philosophy* (1836) established him as a very able mathematician, particularly well versed in the long-standing problem of the "Figure of the Earth." His account of this was the clearest and most accessible to date. A revised version was published in 1860.[515] In his preface to the latter, Pratt expresses regret that he had parted with the earlier copyright, resulting in "the appearance of separate treatises . . . instead of a new edition in one volume." One such was Isaac Todhunter's *Treatise on Analytical Statics* (1853), which used large verbatim extracts from Pratt's treatise.[516]

Pratt also conducted research into an unexpected discrepancy between separate estimates of the length of the meridian arc, as calculated in George

---

[513] While at the Presidency, he served on local committees of the Society for the Propagation of Christian Knowledge and the Incorporated Society for the Propagation of the Gospel in Foreign Parts, and on the committee of Madras Grammar School: *Madras Almanac* (1837), pp.117, 133. His Vepery appointment is in *Madras Almanac* (1845). The toll on his health is mentioned in Cazenove (1867).

[514] The announcement of Hopkins' death in *The Times* newspaper lists Pratt among his illustrious former pupils: Anon. (1866a).

[515] This was retitled *A Treatise on Attractions, Laplace Functions, and the Figure of the Earth* (Pratt 1860).

[516] Though remaining more or less within the law, Todhunter borrowed freely from the work of others, often without acknowledgment. In 1858, one Thomas Lund published a pamphlet accusing Todhunter of plagiarising large sections of J. Wood's *The Elements of Algebra*. Though Todhunter's borrowings were many, he justified his action by the fact that the copyright of Wood's book had expired: see Barrow-Green (2001), pp.197–201. Presumably, Todhunter viewed Pratt's treatise similarly.

Everest's Indian survey of 1847. He began by estimating the mass of the Himalayas, at first believing that their gravitational attraction had affected the measurements, but this was later discounted. He and the Astronomer Royal, G.B. Airy, proposed alternative theories, respectively named *Airy isostasy* and *Pratt isostasy*. These postulated a variable density of the Earth's crust, which, paradoxically, should be less dense beneath mountain ranges than near coasts. Only much later did advances in geophysical instrumentation confirm this prediction. Rather belatedly, Pratt was elected FRS in 1866. Pratt's mathematical expertise was used only to a limited extent by Calcutta University: he served during 1861–63 as one of the examiners in mathematics for its Faculty of Arts.

Pratt himself recorded several of his activities in India. His *Notes Written During the Bishop of Calcutta's Second Metropolitan Visitation* (Pratt 1849) recount a lengthy tour, undertaken between November 1848 and February 1849 to many parts of the country. In this, Pratt describes the cities visited, and the scenery and antiquities, with particular emphasis on the state of churches (of various denominations) and of schools. In a later publication, *Some Account of Endowments & Institutions in Connexion with the Diocese and Archdeaconry of Calcutta*, Pratt (1865) states the work's three aims as:

1. To give the Bishop and Archdeacon a ready opportunity of referring to the terms of Trusts placed under their management, without the necessity of poring over old and sometimes almost illegible parchments.
2. To inform the public regarding the Endowments and Institutions. . . .
3. Very especially, to encourage benevolent persons . . . to make bequests after the patterns here commended to their imitation.

As might be expected, the endowments relate to the cathedral itself, and to schools, chapels and missions throughout the diocese. One, the Calcutta Boys' School, was founded in 1862 "for the sons of parents having only moderate income"; whereas the Calcutta Free School was founded for poor Christian boys and girls "who would otherwise have been left in a state of destitution."

J.H. Pratt was an active participant in the "Science versus Scripture" debate that aroused so much controversy. As both an active and original scientist and a leading churchman, he was well qualified to speak. His book, with the rather unwieldy title *Scripture and Science Not at Variance, or, the Historical Character and Plenary Inspiration of the Earlier Chapters of Genesis Unaffected by the Discoveries of Science*, was first published in 1856. First written "to meet the assertion made by the late Professor Baden Powell that 'all geology is contrary to Scriptures' ", the work was repeatedly updated in seven editions between 1856 and 1872, to take into account not only the collection *Essays and Reviews*, but also Colenso's *Pentateuch*, Darwin's *Origin of Species*, Lyell's *Antiquity of Man*, and works by Huxley, Tyndall, and Lubbock.[517]

Pratt's view was unequivocal: "The assertion . . . that the discoveries of Science are opposed to the declarations of Holy Scripture, is as mischievous as it is false, because it tends both to call in question the Inspiration of the Sacred Volume and to throw discredit upon scientific pursuits." He claims to show how difficulties are met and objections removed; for,

> it is *impossible* that Scripture can, when rightly interpreted, be at variance with the works of the Divine Hand; and that therefore, if difficulties remain at any time not cleared up, they must arise from our ignorance, or from hasty interpretation either of the phenomena before us or the language of the Sacred Record . . . no new discoveries, however startling . . . need disturb our belief in the Plenary Inspiration of the Sacred Volume, or damp our ardour in the pursuit of Science.[518]

He proceeds with much detailed argument on many fronts. The motion of the Earth is compatible with its apparent contradiction in *Genesis* because the latter describes observed, relative, motion as seen by mankind. Likewise, the Biblical six days of creation and the Flood may be reinterpreted in accord with physical laws. In arguing that "All men are one blood", Pratt claims that the differing physical appearances of the races are attributable only to environmental conditions.[519]

Regarding the age of the Earth and the origins of language, Pratt rejects the accuracy of Hindu and Chinese astronomical texts, and the supposed age of Egyptian hieroglyphics, flints and other ancient remains. He believed that Colenso's "arithmetical objections" to Biblical accuracy can be refuted by philology in many cases, and attributed to over-literal interpretation in others. Regarding the alleged impossibility of Moses and Joshua addressing

---

[517] Pratt (1856) and later editions: all quotations below are from the seventh edition of 1872.

[518] Pratt (1856), 1872 ed., pp.1, 5.

[519] In one remarkably wrong-headed passage, he recounts "the concurrent testimony of disinterested observers, both in the West Indies and in the United States, [that an] approximation in the Negro physiognomy to the European model is progressively taking place. This is particularly the case with negroes employed as domestic servants": Pratt (1856), 1872 ed. p.102. Pratt believed that this supposed process was taking place by mere juxtaposition of the races rather than by interbreeding, despite the well-known high incidence of inter-racial liaisons, in India as well as in the West Indies and the United States.

all Israel, Pratt asks: "Does the commander of a great army never address his troops, who are too numerous to hear? Is not his address read to them at the head of their companies?"[520]

In July 1871, Pratt delivered a lecture to the Dalhousie Institute in Calcutta entitled *The Descent of Man, in Connection with the Hypothesis of Development*, which was promptly published in London (Pratt 1871). This is a forthright criticism of Charles Darwin's recent *Descent of Man*, of his earlier *Origin of Species*, and of other recent supporters of evolution. In Pratt's opinion, Darwin's *Descent of Man* "is a work, like all his books, full of facts, but combined together by pure speculation."[521] Like many others with high mathematical accomplishments (such as Hopkins, Stokes, Goodwin), Pratt demanded a higher standard of scientific proof than the biological record was capable of delivering.

Pratt contracted cholera on a visitation to Ghazipur and died there on 28 December 1871. His *Times* obituarist described him as "one of the ablest theologians and most devoted divines . . . that England ever sent to India . . . a quiet earnest worker, solitary in his habits . . . a wise counsellor . . . and an ardent, though undemonstrative contraversialist [sic]."[522]

Also at Calcutta for a time was Charles Baron Clarke (3rd equal, 1856), who joined the Bengal educational department in 1865. In Cambridge, he had been a close friend of Leslie Stephen and Henry Fawcett, and accompanied Stephen on alpine-climbing and plant-collecting expeditions. Clarke's love of botany had been encouraged by his parents in childhood, and it became his life's passion. He briefly held a post at Presidency College in Calcutta, where he taught mathematics, then became inspector of schools in East Bengal (now Bangladesh) with headquarters in Dacca. By 1868, he had built a collection of 7000 plant specimens from East Bengal, which sadly perished in a wreck; but he simply started again.

Clarke recorded his first impressions of India in a long letter to one of the Porter brothers.[523] He remarks that Calcutta is most untruly called "a city of palaces": the houses of the English quarter were anything but palatial, and "the black town consists of swarming hovels". But his teaching duties were

---

520 Pratt (1856), 1872 ed. p.265. No doubt, he would have been well aware of this practice in the British garrisons of the larger Indian cities.

521 Pratt (1871), p.17.

522 Quoted in McConnell (2004).

523 Clarke (ms.1865). This letter, which begins "Dear Porter", is now in the Centre for South Asian Studies, Cambridge University: it is catalogued as sent to John Porter, but James Porter also seems possible. Both William and John Porter were themselves in India at this time.

"exceedingly light", and his class "very eager" compared with Cambridge undergraduates. The average age of his students was nineteen, "all married and fat". Their eagerness was attributable to the need to get a B.A. degree for entry into Government employment. Their mathematical ability did not seem high; but mathematics was just one of about twelve subjects that they had to study, "So that they do not get a fair chance."[524]

During 1869–71 he substituted as superintendent of the Calcutta Botanical Gardens, then resumed as inspector of schools for three more years, before returning to Calcutta in 1874 and transferring to Darjeeling in 1875, from where he extended his botanical travels to Nepal, Bhutan and Kashmir. On his return to England on leave in 1877, he presented 25,000 specimens of 5000 species to the Kew Gardens herbarium, and he collaborated with Sir Joseph Hooker on the definitive *Flora of British India.* This work was deemed of such importance that, on the expiry of his leave in 1879, the government of India appointed him on special duty at Kew.

He returned to India during 1884–87, first as director of public instruction in Bengal, and then as inspector in Assam where he continued his botanical work. He retired in 1887 and spent the next nineteen years as a volunteer at the Kew herbarium. He was a fellow of the Linnean Society and its president from 1884 to 1896. He was elected a fellow of the Royal Society in 1882. As well as his several botanical writings, he published articles on a wide range of other topics, from political economy to music theory. Never married, he latterly lived near Kew Gardens with his brother, when he substituted long-distance cycling for long-distance walking.[525]

William Archer Porter (3rd, 1849) was the son of a Presbyterian parish minister in Drumlee, Co. Down, Ireland, and attended Glasgow University, where he studied mathematics under James Thomson. Proceeding to Cambridge in 1845, he was first admitted to Trinity College, but soon transferred to Peterhouse. Arriving there soon after William Thomson had taken his B.A. degree, Porter had the younger Thomson as his first mathematics tutor: he is perhaps unique in having been taught by father and son in the two different

[524] Clarke also discusses housing arrangements in the European quarter, the price of rooms and servants, and the uselessness of learning Bengalese. He gives a lengthy account of poisonous snakes; and notes a general dislike of the current Governor-General [John Lawrence], who is considered to lack pluck and to be "an ignorant narrow-minded totally-uneducated fool." Finally (without stating his own view), he reports general disapproval of a two-year jail sentence given to an English planter for flogging three servants so brutally that one died: "they say he ought not to have been fined a sixpence, everybody flogs their niggers."

[525] Desmond (2004).

universities. According to Romilly, Porter had been favourite to become senior wrangler, following the withdrawal of "one really good man . . . [who] broke a blood vessel & is gone to Madeira" to recover.[526]

William Porter spent some years as a fellow at Peterhouse, before embarking on a legal career at Lincoln's Inn. He was called to the Bar in 1859 and served as an equity draftsman and conveyancer before his departure for India. He joined the Educational Department of the Indian Civil Service in May 1863, first as Headmaster of the Provincial School at Kumbakonam, a town situated about 160 miles south of Madras. He was soon appointed a Fellow of the University of Madras and a member of its Faculties of Arts, Law and Civil Engineering. He is listed as one of the examiners in mathematics for the Arts Faculty from 1865 to 1882. Between 1866 and 1877, he served for several periods of up to a year as Acting Principal of Presidency College, Madras, one of the main colleges affiliated to the University of Madras.[527]

The Provincial School at Kumbakonam had been founded in 1854, and under Porter's guidance, it was raised to a Government College in 1867 training students up to B.A. level.[528] For a time, Porter also served on the managing committee of the Madras Literary Society & Auxiliary of the Royal Asian Society, a body with a good library of more than 17,000 volumes.[529]

---

526 Bury & Pickles (2000), p.28. William Porter's younger brother, James (9th, 1851), followed in his footsteps from Glasgow to Cambridge, and duly became Master of Peterhouse during 1876–1900, a time when many Scots were among its fellows. For a brief period before that, James was mathematical lecturer at Liverpool's Collegiate Institute. The youngest brother, John Sinclair Porter, was a student of P.G. Tait at Queen's College, Belfast, and served in the Indian Civil Service from 1861 to 1889: Knott (1911), pp.14, 15.

527 The University of Madras had been founded in 1840, but at first was really a school rather than a university. Its first Principal was (Sir) Eyre Burton Powell, a Cambridge graduate from Christ's College, an undistinguished 36th-equal wrangler in 1830 who did not take the Classical Tripos. Presidency College was established in 1855.

528 According to his official "history of service", Porter served as Principal of Kumbakonam College only from November 1874 until June 1878, following furlough to Europe between May 1873 and October 1874: Anon. (1882), p. 206. But this seems merely to reflect a change of title: in contrast, the Kumbakonam College Calendar, Anon. (1908), does not distinguish between headmaster and principal and there he is listed as "Principal" from 1863 until 1872 and again from 1874 to 1878. (During Porter's absence in 1872–74, the Principal was T. Gopala Row. The latter also served as Principal in 1862–63, and joint principal in 1857–62, 1874–75 and 1877–82.)

This is the same college later briefly attended by the mathematical prodigy Srinivasa Ramanujan (1887–1920), whose failure in English led to his withdrawal after just a year. His genius was recognised by G.H. Hardy in Cambridge, on receiving some of his writings: but Ramanujan's brilliant Cambridge sojourn ended tragically with broken health, and an early death back in Kumbakonam.

529 Anon. (1878).

Just what sort of education was provided at Kumbakonam College in Porter's time as Principal? One writer grandly claimed that he turned Kumbakonam College into "the Cambridge of Southern India".[530] It is reasonable to suppose that he promoted a variant of Whewell's programme for a "liberal education", featuring English language and literature, a pro-British version of European and Indian history, mathematics and physics, and instruction in Indian languages. In mathematics, the textbooks were almost certainly those written by Isaac Todhunter. In 1876, some of Todhunter's works (on Euclid's *Elements*, Algebra, Mensuration and Surveying) were published by Macmillan of Cambridge, in adapted or abridged form specifically for Indian Schools, by order of the Indian Education Service.[531] It seems likely that Porter had some say in this decision.

The exact syllabus at the College is known from thirty years after Porter's departure, published in the *College Calendar*.[532] Perhaps the major change was that the high school classes ceased in 1881, and the College concentrated on preparing students for the B.A. degree in just a few of the subjects prescribed by the University of Madras. The College was "open to all classes of the community, but the great majority of the students are Brahmans." Also, "Muhammedans, Uriyas and other backward or indigent classes" were admitted for half the usual fees. Among five rules for dress and behaviour, the quaintest was: "No student shall be allowed to sit in class with his shoes on, unless they are shoes of English pattern and unless socks and trousers are worn also." Staff numbers were quite small: as well as the Principal, there were four lecturers, six assistant lecturers, a "Sanskrit Pandit" and a "Tamil Pandit", plus a gymnastic instructor, clerk and librarian. All these staff and all the students were Indians. In the two-year "First Arts" programme, the timetabled subjects were Mathematics, English, History, Physiology and a second language (either Sanskrit or Tamil); and the third- and fourth-year B.A. courses were English, Science and the second language. Only nine students passed the final B.A. degree examinations in English (four at second class and five at third class), eight passed in science (five second class and three third class), ten passed in either History or in Mental & Moral Sciences, and eighteen in either Tamil or Sanskrit. Clearly, the College was not a large one.

The junior B.A. syllabus in mathematics covered plane trigonometry, some differential calculus, geometrical and analytical conics, plane and solid

530 Vadivelu (1900), p.15.

531 Barrow-Green (2001), p.203. Parts of these works were also translated into Hindi and Urdu (A. Aggarwal, private communication).

532 Anon. (1908).

geometry, algebra, the theory of equations, and spherical trigonometry. The senior B.A. syllabus covered differential calculus, dynamics and statics, hydrostatics and pneumatics, optics, and astronomy (including tides and the shape of the Earth). These, of course, were precisely the subjects emphasised at Cambridge, and two of Todhunter's books were still recommended texts. The syllabus in English ranged through Chaucer, Shakespeare and Milton to more modern writers Jane Austen, Keats, Tennyson, Coleridge, Arnold, Stevenson and Carlyle. The mathematics syllabus that C.B. Clarke taught at Calcutta seems to have been rather similar: though a wide range of topics was covered, these could not be pursued in much depth, because of the conflicting claims of other subjects.

In June 1878, William Porter was seconded from his post as Principal of Kumbakonam College and his services were "placed at the disposal of the Government of India", so that he could be appointed as personal tutor to His Highness the Maharaja of Mysore (Maisur, now Karnataka). In fact, the young Maharaja was a political pawn under the control of the British Residency.

With the overthrow and death in 1799 of Tipu Sultan, the Muslim sovereign of Mysore, military resistance to British conquest was quelled. Tipu's forces, assisted by French officers, had long resisted the East India Company's army, which suffered several major defeats. But Tipu's well-trained and well-equipped army was finally overcome by an alliance of British and Hyderabadi forces.[533] Partition of Tipu's domains followed, but not in a manner that pleased the Hyderabadis, who had hoped for great material gains. Instead, the East India Company—more perfidious than Honourable—insisted that they and the Hyderabadis each hold only a small part of Tipu's former territory, and that descendants of an all-but-forgotten Hindu ruling family of Mysore be re-established as heads of state of the main part. This device enabled the British to exert indirect rule over most of Mysore: the British Resident was in real control, and the cost of the British garrison was met by a punitive charge upon the State of Mysore.[534]

The hereditary leader, Raja Sri Krishnaraja Wodeyar (or Wadiyar) Bahadur III, assumed power at the age of sixteen, without appropriate training. He was soon surrounded by "worthless favourites and men of loose character . . . enjoying undue privileges, and making him a mere tool in their

[533] Wellesley had earlier engineered the defeat of a pro-French faction in Hyderabad, and in return gained the support of its ageing ruler, the Nizam.

[534] Dalrymple (2003), pp.190–203.

hands."[535] In 1830–31, misgovernment by the Raja sparked a rebellion that was put down by British troops, and direct British rule was imposed for the next fifty years. The Raja several times petitioned for his powers to be restored, but this was refused. Yet he remained loyal to the British, and Mysore took no part in the Indian Mutiny of 1857–58.

The Raja had no heir, and for long was content that Mysore should revert to Britain on his death. But, after the Indian Mutiny, the British Government took over the administration of the Indian Empire from the East India Company. During the 1860s, the Raja and many of the British in Mysore were offended by decisions of the India Office in London, that were seen as diminishing the authority of the Governor General of India. At this time, a major debate took place in Britain on the relative merits of annexing Mysore and restoring the maharaja.[536] In 1865, the Raja undermined the case for annexation by adopting a two-year-old successor, an act supported by Major C. Elliot, the Superintendent of Mysore Division. This adopted son was Chamarajendra Wodeyar Bahadur X, to whom Porter later became tutor. In 1867, the British Government at last agreed, in principle, to restore native rule; but the old Raja's death in the following year led to postponement until his successor, now in the care of the British, came of age.[537]

When Porter became tutor to the fifteen-year-old Maharaja in 1878, Mysore state had been in the grip of a severe famine for two years, when about a million died of starvation. In all probability, this had been exacerbated by the disruption of the traditional agricultural economy by high taxes imposed by the British administration, and by its insufficient actions to relieve distress. It was no doubt expedient to plan for the transfer of some power to local rulers, rather than shoulder all the blame for such a disaster.

The old Raja had spoken no English, though he conversed fluently with Europeans in Hindustani. In view of his misdemeanors that led to direct rule,

> the British this time took full responsibility for the education of the young Prince . . . a special school, modelled on the public schools of England, was established at Mysore and later the young Maharaja was given an English tutor, who exercised supervision over his private life. One tutor, W. A. Porter, made this statement about the progress of his royal pupil:

535 Vadivelu (1900), p.4.

536 A petition in support of the latter course was led by John Stuart Mill.

537 Fuller historical accounts are Gowda (1997), Hettne (1978), Gopal (1965), V. Smith (1923), Vadivelu (1900).

> "He now hunts twice a week during the hunting season and has the character of a forward rider. On most other mornings he rides out of exercise. His afternoon amusements are lawn tennis, cricket and driving [with horse and carriage]. He also plays polo one evening in the week."
>
> . . . [but] in his more sober moods Porter had to admit that the Maharaja's [intellectual] attainments have not reached and are not likely to reach a very high standard.[538]

The Government of India had strictly prescribed the nature of the Maharaja's education. His first tutor and official guardian, Lieutenant-Colonel G. Haines, was instructed to:

> look after the moral, mental and physical culture of the Royal pupil, to keep out all political matters from the curriculum of studies, [which] should embrace a sound knowledge of the English language and literature as well as those of Mysore, and that a good physical as well as moral training should be sedulously imparted. . . . The Maharaja might be taught to ride, to swim, to play cricket, and to handle fire-arms and should be encouraged to devote himself successively to those physical and strengthening exercises which are suited to his country, person and age.[539]

The order to "keep out all political matters" from the training of the future ruler underlines the intention that the ruler should be under effective British control. But Haines' appointment lasted for just a year. He was succeeded in 1869 by a Colonel Malleson, who recruited three Indian teachers and a Colonel Meade to form a school with three classes, on the Wykehamist model of Winchester School in England. In July 1870, Malleson reported to the new Governor-General, Lord Mayo, that:

> I am glad to say that the young Maharaja is doing wonderfully well, his progress being as solid as rapid. He is developing a most retentive memory. . . . He takes great interest in cricket and riding. Altogether he is most promising and not the same boy he was this time last year.[540]

---

[538] Hettne (1978), pp.48, 49.

[539] Vadivelu (1900), p.13.

[540] Mayo (mss. 21 July 1870). A few months later, the Maharaja himself wrote to Lord Mayo in a clear childish hand, thanking him for his kindness to relatives in Calcutta, and for the gift of a locomotive: Mayo (mss. 26 Jan. 1871). Another letter to Mayo, by O. Burns, favourably describes a visit to the school, where the Maharaja was "full of eagerness to distinguish himself. . . . He reads fairly, writes well, and is better than his fellows at arithmetic and Geography": Mayo (mss. 15 Feb. 1871).

Malleson was replaced by James D. Gordon in 1871, during Malleson's leave in England, then by Captain F.A. Wilson in 1876, and again by James D. Gordon at the end of 1877. Finally, in July 1878, "Mr Porter, the veteran educationist, who made Kumbakonum the Cambridge of Southern India, was secured, whilst Gordon continued as Guardian."[541] Such a rapid succession of tutors indicates that the teenage Maharaja's education was not continuing to progress well. Though his sporting prowess was developing fast, the same was far from true of his intellectual attainments. For this reason, Porter was called upon to leave his post at Kumbakonam College: he was an experienced educationalist whereas the previous tutors had all been military men. Porter immediately introduced "a few salutary changes. Instead of teaching the Maharaja in the class along with others, Porter acted mainly as private tutor, thereby allowing his Highness to have all his lessons by himself." The Maharaja subsequently developed a particular interest in Physics, showing patience and dexterity in his experiments.[542]

Porter served as tutor until July 1881, and continued as the Maharaja's private secretary until his retirement on 31 March 1882. In 1878, the year of Porter's appointment, the young Maharaja had married "an accomplished princess of the Kalale family, educated in a similar manner."[543] In due course, their first child was born in 1882.

Writing in 1900, the Mysore reporter A. Vadivelu recalled the high esteem in which Porter was held: "It is not too much to say that all the pupils of Mr. Porter realized his hopes. He is regarded by all who remember him with a respect and affection which border on veneration. He introduced an altogether new pedagogical ideal." By 1880, James Gordon (now Sir James) could report to the Government of India:

> that the progress made since Mr. Porter's arrival, in developing His Highness's general intelligence and in giving him a proper mental training, has been marked and very satisfactory. He is now able to read and understand for himself ordinary books and newspapers, and he composes fairly and writes his letters without assistance. His power of observation is keen and his judgment of persons and things remarkably sound. For a boy so young he shows caution and prudence in an unusual degree.[544]

541 Vadivelu (1900), p.15: see also Rice (1897), p.441; Shama Rao (1936), pp.32–36.

542 Shama Rao (1936), pp.39, 40.

543 Rice (1897), p.441.

544 Vadivelu (1900), pp.16, 17.

(But the "boy so young" was now eighteen and had been married for two years.)

As part of his education, the Maharaja was taken on trips to Calcutta and Bangalore, and, in hot weather, to the hills of Ootacamund. As both Guardian and Chief Commissioner, Sir James Gordon played a key role:

> On him . . . devolved the responsibility of the final steps needed to fit both the young prince for his kingdom, and the kingdom for the prince. . . . To the young Maharaja, . . . the system and principles of the administration continued to be the subject of careful instruction on the part of Mr. Gordon, and in 1880 he accompanied Mr. Gordon on a tour throughout the State as the best means of impressing the lessons on his mind, and making him acquainted with the country he was soon to rule.[545]

Recent harvests had been good and prosperity was returning to Mysore after the famine: it was an auspicious time both for the lavish tour of his domains and for the coming handover of power.[546]

Chamarajendra Wodeyar X's enthronement took place with great pomp on 25 March 1881. The enthronement ceremony was performed by the Governor of Madras, the Right Honourable W.P. Adam. Gordon and Porter would certainly have been in attendance. The administrative machinery remained in British hands, or in those of loyal Indian ministers. Two Dewans, or chief ministers, served the young and not very clever Maharaja: both were Brahmins educated by the British at Madras High School, and both "emerged as complete autocrats."[547] Ample protection was afforded to the growing number of British settlers and planters who had come to Mysore in search of fortune. Despite its rendition to Indian rule, Mysore effectively remained as much under British control as any other part of British India.

The Maharaja's reign during 1881–94 brought some educational improvements to Mysore. The Kannada and Sanskrit languages were supported by improved colleges, several libraries were founded, and a Maharani's Girls' School was begun in Mysore city.[548] The Maharaja died young and unexpectedly, on 28 December 1894, during a visit to Calcutta where he contracted diphtheria. He had made little personal impact on his subjects: in the words of one Mysore journalist, "Chamaraja Wadeyar is to us but a handsome prince

[545] Rice (1897), p.441ff.

[546] Hayes (1887). Unfortunately, the author has been unable to see this work: the British Library copy is missing and no other is recorded in U.K. libraries.

[547] Hettne (1978), p.68.

[548] Hayavadana Rao (1929), pp.498–503.

Figure 15. Portrait of the Maharaja Chamarajendra Wodeyar Bahadur X. [From Shama Rao (1936), frontispiece. Courtesy of Higginbothams, Bangalore.]

who died early."[549] But the rendition of Mysore was hailed as a success by the British, who approved of the innocuous Maharaja:

> Dignified and unassuming, his bearing was that of an English gentleman. An accomplished horseman and whip, fond of sport, a liberal patron of the turf, and hospitable as a host, while at the same time careful in observance of Hindu customs, he was popular with both Europeans and natives. His palace was purged of all former evil associations, and the Court of the Queen in England was not purer in tone than that at Mysore under the

549 Quoted in Hettne (1978), p.68.

> late Maharaja. He was devoted to his family, and of a cultured and refined taste which led him to take special pleasure in European music and in works of art.[550]

In contrast with her late husband, the Dowager Maharani proved to be strong and influential: "for twelve years when her son was a minor she ruled the country from behind the purdah."[551]

William Porter did his best for the Maharaja and for the British Raj. In return, he was quite well rewarded. His Tutor's salary had been 1200 rupees p.a., an increase of 200 rupees over that as Principal of Kumbakonam College. In 1882 he retired to Britain with a handsome pension of 3000 rupees p.a. He seems first to have settled in St Andrews, for he enrolled there as a very mature student in the University's course of chemistry during the session 1882–83.[552] It is likely that there he stayed in the house owned by his brother-in-law P.G. Tait, a second home close to Tait's beloved golf courses. Later, Porter moved to Edinburgh, yet closer to the Tait family: one of the family members, William Archer Porter Tait (b. 1866), was named after him. It is possible that Porter's health, like that of so many others, had been impaired by his long stay in India: he died in Edinburgh in 1890, aged sixty-four or sixty-five.

Several other top wranglers had connections with the Indian subcontinent. Augustus De Morgan (4th, 1827) was born at Madura in south India, the son of an Army Colonel: but he spent only the first three months of his life there, before the family moved to Worcester in England. Yet India left its mark, for the infant Augustus had contracted an eye disease that resulted in the loss of sight of one eye and impaired the other. To this is attributed his often-stated dislike of the countryside and of nature, and his preference for the city and intellectual pursuits.

Anthony W.W. Steel (2nd, 1859) was also born in India, and attended Martinière College in Calcutta before entering Caius College in Cambridge. James W.L. Heaviside's Indian connections were more indirect: but, as Professor of Mathematics and Registrar of the College of the East India Company, he would have taught many young men destined for service in India and elsewhere in Asia. The same is true of Joseph Wolstenholme, as professor of mathematics at the Royal Indian Engineering College in London.

---

550 Rice (1897), v.1, p.449.

551 Barton (1934), p.145. Their son, the Maharaja Sri Krishnaraja Wodeyar Bahadur IV, ruled ably from 1902 to 1940. Among the achievements of his reign was the founding in 1916 of the University of Mysore: "the first University founded in our own time by an Indian Ruler for the benefit of his people" (Besant 1924).

552 Smart (2004).

Henry Carlyon Phear (2nd, 1849) had two brothers who were also wranglers: Samuel George Phear (4th, 1852) and John Budd Phear (6th, 1847).[553] Henry Phear spent his life as an English barrister and conveyancer, having trained at the Inner Temple; Samuel Phear went on to become Master of Emmanuel College, Cambridge; and John Budd Phear (6th, 1847) became a prominent Indian lawyer.

John Budd Phear spent some years in Cambridge as a fellow at Pembroke College, when—like so many others—he wrote two mathematical texts. After being called to the bar at the Inner Temple in 1854, he practised in England before his appointment in 1864 as a judge of the high court of Bengal. According to his biographer:

> As a judge Phear prided himself on his freedom from racial prejudice and was particularly noted for his refusal to trivialize cases of assault brought by Indians against Europeans. In Calcutta's insular Anglo-Indian community such behaviour was soon translated into the perceived sin of "partiality for the natives", a view heightened in 1867, when Phear and his wife gave an Indian name to their first-born daughter, Ethel Kamini. . . .
>
> He was respected by many Westernized Bengalis but his belief that India's social and political advancement hinged on the processes of Anglicization and female emancipation alienated the more radical members of Bengal's intelligentsia. Phear only moved comfortably among those Bengalis who acknowledged the superiority of Western achievements; it was beyond doubt to him that Bengal's indigenous culture, which he described in *The Aryan Village in India and Ceylon* (1880), represented a lesser, primitive stage of civilization.[554]

In 1876, Phear received a knighthood and was appointed Chief Justice of Ceylon. During a three-year stay, he revised the colony's legal code. He returned to England in 1879, settling in Exmouth, Devon, where he played an active part in public life as an alderman, up to his death in 1905.

Four more Cambridge graduates of this time were involved with the political administration of India. The Liberal MP, Samuel Laing (2nd, 1831), was appointed by Lord Palmerston as financial minister to the Governor General of India during 1860–65. And Henry James Sumner Maine (42nd SO and 1st classic, 1844) was legal member of the Governor-General's Council during 1862–69 and Vice-Chancellor of the University of Calcutta during 1863–69. Maine had been Cambridge's Regius Professor of Civil Law, and was later

[553] They were also relatives of the Budds of Taunton, Devon, several of whom were wranglers. The Phears, like the Budds, were probably all pupils of William Hopkins.

[554] Hughes (2004).

Master of Trinity Hall. The remaining two never visited India: the Conservative MP John Eldon Gorst (3rd, 1857) was under-secretary of state at the India Office in London during 1886–91; and the Liberal Henry Fawcett (7th, 1856) was dubbed the "member for India" on account of his careful scrutiny of Indian bills before the British Parliament.[555]

Finally, one must spare a thought for Robert Braithwaite Batty (2nd, 1853), who relinquished the comfortable life of a fellow at Emmanuel College to become a missionary. He arrived in India in 1860 and died the following year, of dysentery, at the Mission House, Amritsar.

The African Bishops: J.W. Colenso, C.F. Mackenzie, H. Cotterill

Among all our wranglers, John William Colenso was perhaps the most colourful and controversial.[556] Born in 1814, he was the son of a mineral agent for the Duchy of Cornwall, who also had private business interests in tin mining. But, when John was around fifteen, his father suffered a major financial loss when a mine flooded, and he seems then to have deserted his family. His mother died shortly afterwards, and John, as eldest son, was left responsible for his three siblings. Without other financial support, he became employed as an usher at a school in Dartmouth. Aided by the young schoolmaster for whom he worked, Colenso somehow raised enough money to enter St John's College as a sizar. There, the college provided further support on the recommendation of his tutor, John Hymers. Later, Colenso earned extra money from translations and from a small mathematics text he had written; and, with William Hopkins' paid assistance, he became second wrangler in 1836. Though promptly elected a fellow, his financial worries were far from over.

Always serious-minded and religious, Colenso was ordained a priest at the age of twenty-five. Next, he was recruited to teach mathematics at Harrow school by its headmaster, Dr Longley, whose path was again to cross Colenso's at a later date.[557] Colenso was responsible for a Harrow scholars' boarding house which unfortunately burned down, and which increased his debts to the then huge sum of £5000. Obliged to leave Harrow to try to meet these

---

555 It is significant that both C.B. Clarke and W.A. Porter were close friends and correspondents of Fawcett: see Stephen (1885).

556 His life and works have been the subject of several studies, notably G.W. Cox (1888) and Hinchliff (1964).

557 The study of mathematics at Harrow became compulsory only from 1836, about the time of Colenso's recruitment: Dubbey (1978), p.14.

debts, he returned to St John's as a tutor. There, in 1842, he met and wished to marry Frances Bunyon, but he could not afford to leave his fellowship. Spurred on to earn money, in the next year he published his *Arithmetic for Schools* (Colenso 1843), a work which he did not greatly esteem, but which turned into a best-seller used by generations of schoolchildren. He wrote several other mathematical textbooks, some of which were republished in revised editions, along with further books of problems and solutions.[558] In 1846, aided by relations of his fiancée, he secured a church living at Forncett St Mary in Norwich, and he and Frances were married. They seem to have remained a devoted couple, and had five children.

Colenso had for some time wished to be a missionary, but was unable to do so until he cleared his debts. He became an enthusiastic supporter of the unorthodox theological views of Frederick Denison Maurice (1805–72), though Maurice was later to reject Colenso's interpretations of his works.[559] Colenso may have misinterpreted Maurice's writings, but he certainly shared Maurice's flair for controversy.

In Forncett, Colenso was involved in building a new school in the parish and in modernising its syllabus, and he also took private pupils. But he thought his rural parishioners ignorant, and his clerical neighbours out-of-date and unreceptive towards progressive ideas. In a book of *Village Sermons*, he argued that modern science led to a better understanding of God, and that in missionary work it was wrong to "uproot altogether the old religion of the heathen mind."[560] Though conventional enough views today, these were not so when written, and were to lead Colenso into trouble. Much interested in foreign missions, Colenso maintained contact with his brother-in-law, T.F. McDougall, a missionary in Borneo who became Bishop of Labuan. He also became local secretary of the Society for the Propagation of the Gospel, and was connected with the Colonial Bishoprics Fund. In 1853, Bishop Gray of Cape Town offered Colenso the newly established bishopric of Natal, after

558 The most notable are Colenso (1841; 1846; 1851).

559 While a student at Cambridge, Maurice had been a Unitarian, unable to subscribe to the Thirty-Nine Articles, and so unable to graduate. But he became an Anglican in 1829, and in 1835 wrote a work defending the retention of the Thiry-Nine Articles as a condition of graduation! He became professor of English Literature at King's College, London in 1840, but was forced to resign in 1853 on publication of his widely unpopular *Theological Essays*, which were criticised for unorthodox views on the existence of Hell and eternal punishment. He was later involved in the more practical concerns of Christian Socialism and Working Men's Colleges; and, for a short time before his death, he was professor of Moral Philosophy at Cambridge.

560 Quoted in Hinchliff (1964), p.49.

another had declined the post.[561] After some delay, Colenso accepted, was consecrated near the end of the year, and reached Natal in January 1854 for a preliminary tour.

The colony of Natal was still a precarious one, cut off from Cape Colony by uncolonised Zulu lands, and by an independent immigrant community of Voortrekkers of Dutch ancestry. In his diocese, Colenso found only two active clergy, James Green, the priest at Pietermaritzburg (still a village), and W.H.C. Lloyd in Durban. Green too was a Cambridge mathematics graduate: after previous study at Durham, he had been sixteenth wrangler in 1844, but this was not bond enough to maintain good relations with Colenso. Colenso's two colleagues had very different theological views; Green was a "Tractarian of the most advanced kind", and Lloyd "a Church of England parson to the backbone, He was old-fashioned. He was a Church and State man" shocked by Colenso's Biblical criticism.[562]

Colenso described his first visit and his missionary outlook in *Ten Weeks in Natal*, written during the long voyage home. This book contained some revolutionary thoughts that led to the first attacks on him. Among these was his suggestion that the Church should allow polygamists to be baptised, as it seemed a sin to make a convert choose between baptism and disposing of his extra wives.

Back in England, he recruited several to join his team, among them Charles Frederick Mackenzie as archdeacon. The Scots-born Mackenzie had been 2nd wrangler in 1848, tutored by Hopkins. Tall, strongly built, and prematurely balding, Mackenzie was a keen sportsman who played cricket and rowed; a gentle, plain-speaking man of simple practical Christian faith, but little interested in theological and metaphysical debate. Alfred Barry, his Cambridge classmate under Hopkins, paid tribute to Mackenzie's mathematical acuteness, but was not otherwise impressed by his ability.[563]

As a fellow of Caius College, Mackenzie was friendly with two other Hopkins wranglers, William Bonner Hopkins and Harvey Goodwin, the latter of whom later wrote his memoir. He assisted W.B. Hopkins (2nd, 1844), who was a curate in Cambridge, by visiting elderly parishioners. Then he himself obtained a curacy at nearby Haslingfield, which he combined with his math-

561 Gray, briefly back in England, suffered a breakdown through overwork about this time. He was later bitterly to regret appointing Colenso.

562 Wirgman (1909); Hinchliff (1964), pp.60, 62. The "Tractarians" were followers of the Oxford theologian, John Henry Newman, whose *Tracts for the Times* aimed to impose more definite doctrine and discipline on the Church of England.

563 After the senior wrangler Isaac Todhunter, Barry and Mackenzie had tied for the second Smith's Prize; but, in accordance with Smith's bequest, it was awarded to Barry as he belonged to Smith's old college of Trinity: Goodwin (1864).

ematical duties at the University. With Goodwin, he assisted at a charitable Cambridge Industrial School "established for the purpose of rescuing poor boys from the dangers of idleness."[564]

Mackenzie had mixed feelings about remaining in Cambridge. He wrote to a sister that:

> Sometimes I feel almost inclined to repine at my lot because it is so prosperous, and to wish that I had some of those afflictions which are so often spoken of as necessary for men. . . .
>
> I do not think that the respect which is paid to "a good degree" is good for me. The other day, [Archibald] Smith, our late tutor, offered me . . . one of the Secretaryships to the Cambridge Board of Education. At first I declined it, as mixing me up with men so much my seniors, and as pushing myself forward. But he overruled my objection by saying that my *position* in the University was quite sufficient to justify it, and so by Hopkins' advice I accepted. I mention this to shew what I consider the idolatry of Mathematical and Classical talent which exists here.[565]

Though disapproving of some colleagues, he believed that in College "much good can be done here, if one can only consider it as one's parish." He assured his sister that:

> I can hardly think of a more important place in England, except perhaps the head-mastership of a school, and even that falls short of this place in one respect, that without doubt a considerable number of the Fellows do not consider their responsibilities but may be induced to do so by a few good examples; and so a little leaven leavening the whole lump, there would be a great increase of good influence brought to bear upon the flower of England's upper classes, at an impressionable age, and one at which character is *set* for life.[566]

Undecided about going or staying, he discussed his missionary plans with W.B. Hopkins, Goodwin, and with his sisters in Scotland. Goodwin persuaded him not to accept a post in Delhi; but he did not object to Mackenzie's accepting Colenso's offer to go to Africa. Goodwin explains his reasoning in his *Life of Bishop Mackenzie*:

> I did not think that the Delhi mission was the best for him . . . ; his power of languages was not great, and the peculiar openness and simplicity of

564 Goodwin (1864), p.43.

565 Goodwin (1864), p.35.

566 Goodwin (1864), pp.43, 66.

> his character seemed to me not suitable for dealing with the accomplished civilized infidelity of well-educated natives.
>
> [But later], it seemed to me, that if go he must, the Natal opening was a very suitable one. I thought that his fine temper and irresistable lovableness would tend to smooth the difficulties . . . and I thought that he would be happier planning missions amongst the untaught Kafirs, than in dealing with the objections of acute Hindus.[567]

Mackenzie, still undecided, at first refused Colenso's offer; but later accepted after hearing some sermons by Bishop George Selwyn of New Zealand.[568] Accompanied by a sister and by a youth recruited from the Cambridge Industrial School, Mackenzie sailed from Liverpool with the rest of the Colenso party on 7 March 1855. A farewell sermon, delivered by Harvey Goodwin in Trinity Church, Birkenhead, was later published.[569] During the journey, the party studied the rudiments of the Zulu language under Colenso's instruction. Later, Mackenzie was joined by a second sister, who became very active in missionary affairs.

Colenso was this time accompanied by his pregnant wife and four small children. The immediate need was to build a cottage and a chapel in his mission territory at Ekukanyeni, in the countryside a few miles east of Pietermaritzburg. This was given the very English name of Bishopstowe. Colenso himself helped with cutting timber and making bricks. Having recently learned the Zulu language, he founded a printing press, and within just a few months he published a Zulu–English dictionary, a Zulu grammar, and a revised Zulu translation of St Matthew's Gospel, all prepared by himself. Further works quickly followed, among them his Zulu translation of the entire New Testament, plus the books of Genesis, Exodus and Samuel, and educational works on geography, geology, history and astronomy. Colenso's incredible industry turned Ekukanyeni into a "model mission station. It contained a printing press, a school, a theological college, a farm, a smithy, a carpenters' shop, a brick-field, and a church."[570]

In other respects, however, Colenso's work was not going well. He quarreled with both Lloyd in Durban and Green in Pietermaritzburg. He tactlessly

---

567 Goodwin (1864), pp.74, 88.

568 George Selwyn, brother of the Lady Margaret Professor of Divinity, has the dubious distinction, among all future bishops of this time, of coming lowest in the Mathematical Tripos, as 21st junior optime; but he won an impressive second place in the Classical Tripos.

569 Goodwin (1855).

570 Hinchliff (1964), p.68.

suggested to Green that he should resign, and he replaced Lloyd by Mackenzie. But Mackenzie was immediately embroiled in a dispute with his white-settler congregation, centring on Colenso's insistence that Mackenzie wear a surplice and introduce both a new prayer for the Church and a collection. Colenso was denounced for "popery", and Mackenzie was happier at his missionary parish of Umhlali than ministering to his contentious urban flock.

The quarrel of 1857–58 with Green had erupted over Colenso's theological teaching concerning the Eucharist, which Green thought heretical. Green raised the matter with the metropolitan Bishop Gray, who consulted Bishop Wilberforce of Oxford; but Gray ruled against Green, though describing Colenso's views as "vague and unsatisfactory." Undoubtedly behind much of the unrest was the belief that Colenso was too much a "friend of the kaffir." But Green's antipathy may well have been more personal: he supported a different faction of the Church, and perhaps considered himself at least as well qualified for the bishopric as was Colenso.

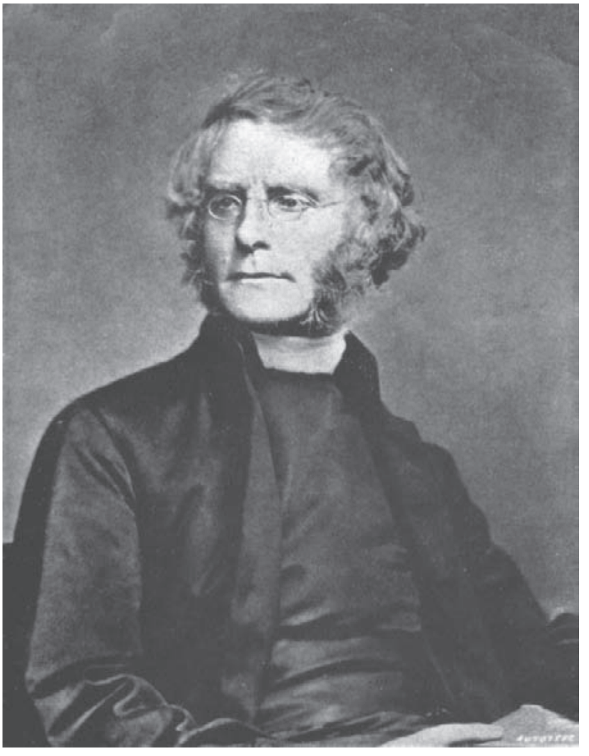


Figure 16. Bishop William Colenso, from an 1864 photograph by J.E. Mayall. [From Cox (1888), frontispiece to v.1.]

Meanwhile, Bishop Gray was keen to establish a new missionary diocese in Zululand, north of Natal, and wished to appoint Mackenzie. Colenso at first supported the proposal, but later withdrew his approval when Mackenzie sided with Green in questioning Colenso's leadership. There was also concern that Gray was too ambitious to extend the boundaries of his jurisdiction. Though Gray was nominally the Metropolitan Bishop of all Africa, both Colenso and Henry Cotterill, the Bishop of Grahamstown, questioned Gray's authority over territory beyond the British colonial settlements. Colenso himself even considered taking on the planned mission in Zululand.

In the end, the explorer and missionary David Livingstone was instrumental in diverting the new mission to Central Africa rather than Zululand. Livingstone, a Scots Presbyterian missionary employed by the London Missionary Society, had already undertaken remarkable journeys of exploration. He returned to Britain at the end of 1856 to campaign on behalf of the native peoples. There, his account of *Missionary Travels in South Africa* (1857) aroused much interest and he received many lecture invitations. On 4 December 1857, he spoke in the Senate House of Cambridge University. In the chair was another of our wranglers, Henry Philpott (1st, 1829), now Master of St Catharine's College. Livingstone's lecture led directly to the founding of the Oxford and Cambridge Mission to Central Africa. This received influential support from the politician Lord Brougham, and it was later renamed the Universities' Mission to Central Africa when supported also by universities in Dublin and Durham.

The November 1859 Report of the Cambridge Committee stated its "hope to be able at an early period to send out not fewer than six Missionaries under the direction, if possible, of a Bishop."[571] But the Government had its reservations, for Central Africa was not a British colony, and trouble with Portuguese and other slave traders in the region could be expected. Livingstone, too, was anxious about possible failure of the mission. In its support, he had minimised the dangers arising from inter-tribal conflicts and slave-traders, from malaria, and from the difficult terrain and hard-to-navigate rivers, all of which he knew well.[572]

When Bishop Gray of Cape Town visited England in 1858, he considered it expedient to support this plan in preference to raising a rival subscription for Zululand. Conveniently, Mackenzie was also back in Britain, and was selected to lead the mission. Before returning to Africa in November 1860, he went on a fund-raising tour of England. Meanwhile, at a Convocation of

571 Quoted in Goodwin (1864), p.209.

572 Jeal (2001), p.234.

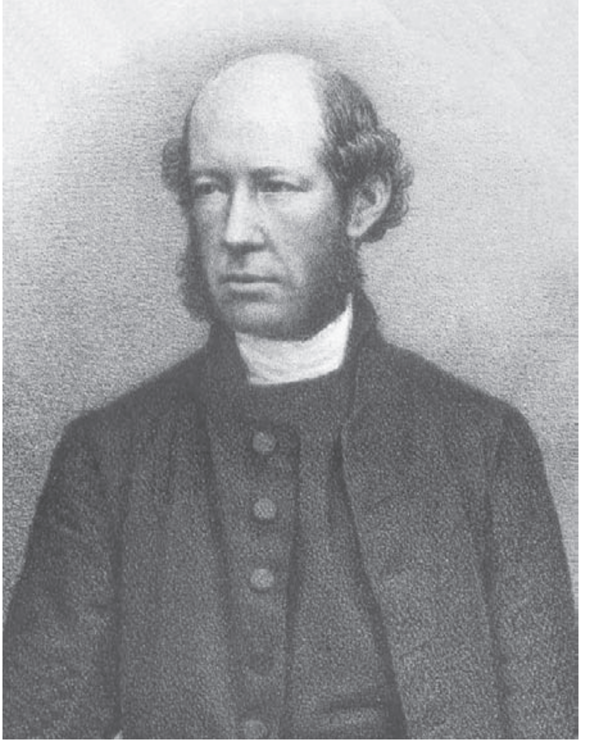


Figure 17. Bishop Mackenzie. [From Goodwin (1864), frontispiece.]

Canterbury, the English bishops recommended to Bishop Gray that Mackenzie be appointed Missionary Bishop of Central Africa. On 1 January 1861, Mackenzie was consecrated as the first ever Missionary Bishop of the Church of England. Later that month, he and his party of missionaries and servants set off on their travels, full of hope and enthusiasm. They rendezvoused with Livingstone and his party on February 9 at Kongone, at the mouth of the Zambezi. Their ship had towed Livingstone's new steamer, the *Pioneer*, an overdue replacement for his worn-out earlier vessel.

Mackenzie at first became a good friend of his fellow-Scot Livingstone, and reluctantly heeded his advice to delay ascending the Shire and Zambezi rivers until a better season for travel. While waiting, he amused himself by writing a mathematical paper on the "Method of Least Squares." In December 1860, he had written to a friend that: "I like mathematics; I liked teaching; and yet I felt the change like a breathing of fresh air, like working at a thing my heart was engaged upon; I am still fond of mathematics . . . but my real best self is wrapped up in the hope of rescuing some of God's wandering sheep. . . ."[573]

Even more reluctantly, he agreed to Livingstone's wish to first explore the Rovuma river, which Mackenzie believed "would transform us from a missionary body . . . into an exploring party." But Mackenzie was dependent on Livingstone's help, and Livingstone rejected Mackenzie's request that he first escort them to their planned base on the bank of the Shire river, before setting off on his own exploration. Livingstone had earlier recommended that the mission should purchase its own steamer, and he was unhappy that it instead relied on him for transport. With different agendas, and with very different religious views, it is not surprising that relations between Livingstone and Mackenzie began to sour.[574]

The trip up the Rovuma proved unprofitable, with several on board having to be treated for fever. Of this, Mackenzie off-handedly wrote that "My experience would lead me to say that the cure is worse than the disease, but my attack was a slight one." Furthermore, Livingstone's brother Charles recorded that Mackenzie "once, to our utter horror, gave a Rovuma alligator an opportunity . . . of immortalising himself by devouring a live Bishop! Fortunately, the monster was not ambitious of such renown."[575] In terms of missionary work, the Rovuma excursion was worthless; and Livingstone's behaviour typified his passion for exploration first and missionary work a distant second.

Goodwin describes several other incidents which suggest that Mackenzie was unusually unlucky or accident-prone. At Natal, he got hopelessly lost on a journey without a compass; and his hut at Umhlali was burned down by a carelessly placed candle. Like most missionaries, he had no experience of the conditions he found himself in: the placid river Cam where he had rowed was a far cry from mosquito- and crocodile-infested African streams. Soon, his luck was to run out completely.

The *Pioneer* finally set off up the Zambezi and entered its tributary the Shire. This proved to be less-easily navigable than Livingstone had said, and many contracted fever. But Mackenzie remained upbeat, writing to a sister on May 16 that the whole party was well and he was "in perfect health. We think very little of the fever; but take fifteen or twenty grains of the mixture of calomel, quinine, etc., which Livingstone has found efficacious, lie by for

[573] Goodwin (1864), pp.267, 313.

[574] Jeal (2001), pp.235–238.

[575] Goodwin (1864), pp.299–300.

a day or so, and then get up, a little weakened. In about a couple of days we are entirely set up."[576]

Though several times delayed by running aground in shallows and by having to stop to cut wood for fuel, on July 8 the *Pioneer* reached its destination of Chibisa's. Led by Livingstone, the party headed inland on foot to the planned site for the mission station among the Mang-anja people. The Mang-anja, however, were under regular attack from the stronger Ajawa, who captured many and sold them as slaves. Mackenzie had reluctantly given in to Livingstone's demand that they should all carry arms, and the missionary party was soon involved in rescuing groups of slaves from their captors. By the time that they reached their base at Magomero, some seventy difficult miles from Chibisa's, their numbers had grown to about a hundred.[577]

There, Livingstone left them, returning to the *Pioneer* and more travels. The mission soon grew to a considerable settlement of huts. Food was bought from their Mang-anja neighbours in exchange for lengths of cloth. The many children too young to work underwent a sort of military drill to keep them in order, because none of the party yet knew enough of their language to teach them. The mission received many requests for assistance against incursions by the Ajawa, some of them fraudulent. Mackenzie's sister and the wives of the other missionaries had not yet arrived, and the bishop much looked forward to their civilising influence on the native women, "some of them wild and rude, and some of them worse, but I hope the influence of our ladies will tell upon them."[578]

Mackenzie was anxious to restore peace to the district around his mission. After a meeting with several village chiefs, he finally and unwisely lent them his support against the Ajawa. With the armed missionaries at its head, a party of about a thousand Mang-anja drove the Ajawa from their settlement. It was on Livingstone's advice that the Universities' Mission to Central Africa had instructed Mackenzie to establish his mission among the Mang-anja: no one had then realised that he was being sent into a war zone, with the stronger Ajawa about to displace the Mang-anja. Mackenzie did not live to know that his mission would soon have to leave Magomero, and that the Mang-anja would be reduced to famine and misery.

One of Mackenzie's sisters had married the Archdeacon of Pietermaritzburg, but the other was keen to join his mission, along with the wives of

[576] Goodwin (1864), p.306.

[577] Goodwin (1864), pp.318–330; Jeal (2001), pp.239–240.

[578] Goodwin (1864), p.350.

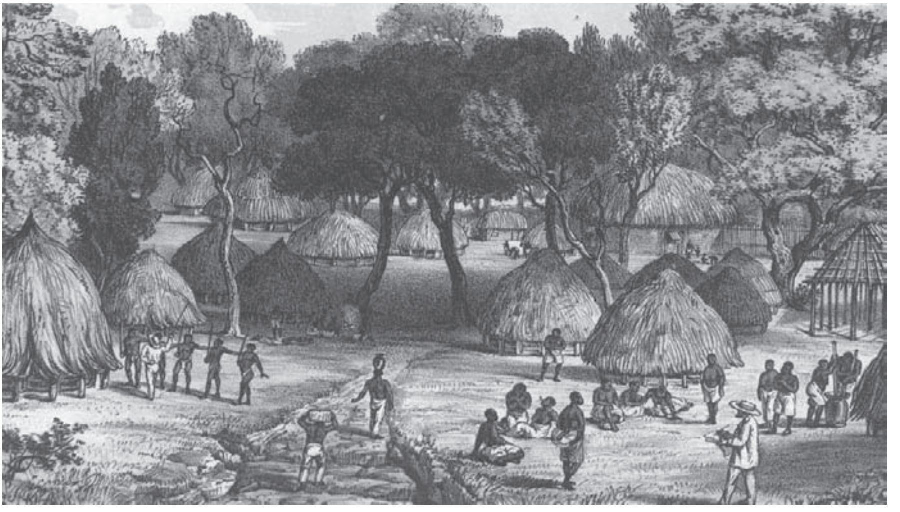


Figure 18. Mission Station, Magomero. Drawing by C. Meller, October 1861. [From Goodwin (1864), facing p.331.]

several other missionaries. Mackenzie arranged to meet the party of ladies at the confluence of the rivers Rou and Shire, around 1 January 1862, where they were to be delivered by Livingstone in the *Pioneer*. Departing from Livingstone's recommended but circuitous route, an advance party ran into hostile villagers and had to retreat. After other difficulties, a small party led by Mackenzie and his missionary colleague Burrup set off down the Shire by canoe. Burrup was especially keen to meet his recent bride, who was in the ladies' party. Thinking themselves too late, the group eventually reached the Ruo mouth on January 13, only to learn that Livingstone would not arrive for some further time. Being ill-received by the village chief, they decided to move on downstream.

Camping overnight on the way, they were so tormented by mosquitos that the boatmen asked to proceed by moonlight. In what was a fateful decision, Mackenzie agreed; but one of the canoes hit an unseen obstacle and filled with water, soaking the baggage. The greatest loss was all their medical supplies, especially the precious quinine. Rather than immediately heading for assistance, Mackenzie decided to stay on an island named Malo to await the *Pioneer*. Both he and Burrup were already suffering from dysentery, and they were soon struck down with fever. There, Mackenzie drafted his last letter, soliciting funds for a steamer from the boat clubs of Oxford and Cambridge Universities. Mackenzie became delirious by January 20, and he died on the 31st, with Burrup barely able to conduct his burial service. He was only thirty-six years old. Burrup struggled back to Magomero with the sad news, and himself died on February 22. The ladies' party did not learn of Mackenzie's and Burrup's deaths until they reached Chibisa's on March 4.[579]

A rude bamboo cross was set up in March by Wilson and Kirk, two of the party accompanying the ladies, but the path was so entangled that Miss Mackenzie could not get to it. A substantial wooden cross was later erected by David Livingstone: this is shown in Figure 19. As Owen Chadwick remarks in his book *Mackenzie's Grave*, "It is somehow symbolic of Livingstone's relations with Mackenzie and his mission, relations always well-meaning but not always effectual, that he should have erected the cross in the wrong place."[580]

Harvey Goodwin's *Memoir*, published in 1864 soon after Mackenzie's death, is largely based on Mackenzie's own letters to his sisters and friends: all profits

Figure 19. Wooden cross erected by David Livingstone to mark the grave of Bishop Mackenzie. [From Goodwin (1864), p.439.]

579 Fuller details are in Goodwin (1864), Chadwick (1959) and Jeal (2001).

580 Chadwick (1959), p.176. The later sad story of the mission is also told by Chadwick: its forced withdrawal from Magomero, attempts to establish it in other, more-peaceful sites, the brief appointment of a new missionary bishop, William George Tozer, the final closure of the mission and Tozer's resignation.

from its sale went to the Universities' Mission to Central Africa. But Mackenzie's mission had been a tragic fiasco, marred by inadequate planning, bad decisions and even worse luck.

Back in Natal, Colenso's well-meaning desire to improve the lot of the Zulu people, and his controversial theological writings, led him into ever greater conflict with the Church authorities. His publication in 1861, by his own press, of *St Paul's Epistle to the Romans: Newly Translated, and Explained from a Missionary Point of View* elaborated his contentious interpretations.[581] Both Green and Colenso's new archdeacon, Fearn, objected to the work and again called in Archbishop Gray to advise them.

Colenso pressed on with a further work, this time on the Old Testament: the *Pentateuch and the Book of Joshua, Critically Examined* (Colenso 1862). The first part was roughly printed at his press in 1862, just before he and Gray separately sailed to England. Shortly before its appearance, the volume *Essays and Reviews* had caused public outcry in England and had been condemned by the Anglican bishops. As already mentioned, one of the most controversial of these essays was by another mathematician, Baden Powell of Oxford, who had supported Darwin's theory of evolution. *Essays and Reviews* contained many contentious suggestions, foremost of which were that the Pentateuch was not a single composition by Moses, directly inspired by God, but the product of various hands; that the Biblical picture of the Universe was not necessarily free from scientific inaccuracy; and that Christian belief needed to be reconciled with Darwin's theory of evolution, in his recently published *Origin of Species*.[582]

Colenso sailed straight into this controversy, for he too cast doubt on the divine, and so unquestionable, origin of the Pentateuch. He did so by concentrating on points of detail, rather than on the big issues, employing his mathematical—or rather arithmetical—skills to demonstrate their literal impossibility. For instance, he demonstrated that all species of animals could not have entered Noah's ark; and he calculated how many Israelites could have stood shoulder to shoulder within the court of the tabernacle, given its known dimensions. He estimated that it could have held only 5000, a very

[581] Among these, he suggested that Christ's death redeems all men everywhere whether they have heard of Him or not, and that unconverted heathens are not automatically condemned to eternal damnation as previous missionaries had taught. Baptism is merely "a proclamation of the accomplished fact that all men share already in Christ's death and resurrection." Colenso (1861): see also Hinchliff (1964), p.80. Hinchliff gives a much fuller account of Colenso's theology than is appropriate here.

[582] *Essays and Reviews* was discussed in Chapter 7, pp.159–162.

small fraction of the total population, despite the statement in *Leviticus* 8:14 that the whole assembly of Israel had gathered to hear Moses and Joshua.

The English bishops had met before Colenso's return to England, and decided to invite him to suppress his works, which many thought heretical. Colenso was incensed that he had been judged in his absence, and refused to meet the bishops unless individually. He pressed ahead with the republication, in England, of the first part of his *Pentateuch and Joshua*. It proved a huge popular success, with nearly 8000 copies sold within three weeks,[583] and there was a torrent of pamphlets seeking to refute his views. Three months later, in February 1863, the newly appointed Archbishop of Canterbury convened meetings of all the bishops of England, Ireland and the Colonies to discuss the Colenso affair. The new Archbishop was none other than Charles Thomas Longley, the former Harrow headmaster who in 1838 had appointed Colenso to teach mathematics. Forty-one bishops signed a statement (with just one abstention) condemning *Pentateuch and Joshua* and urging Colenso to resign. Strangely, the equally contentious parts of his commentary on *Romans* were largely overlooked.

Colenso's reaction was defiant, but attacks came from all sides. A further committee was appointed to draw up a detailed report; the general public was warned that the book was dangerous; Colenso's old mentor F.D. Maurice joined in the attack; and several critical works were published. Sales of the later parts of Colenso's *Pentateuch and Joshua* dwindled as his reputation plummeted and his notoriety grew. Even his old school primer on arithmetic was shunned by some. But Colenso had some supporters too: in January 1863 a dinner was held in London in his honour. One who attended was his old undergraduate friend, J.J. Sylvester.[584]

Nowadays, it is too easy to dismiss Colenso's theological quibbles, and his enemies' refutations alike, as quarrels of little significance. But, in the early Victorian age, the Bible was an all-pervading influence and theological issues were passionately debated by clergy and laity alike. What now may seem obscure and unimportant details of doctrine, of interest only to theologians, then aroused strong passions throughout intelligent society.

Because the English bishops could take no further action, on Gray's return to Cape Town he summoned a Metropolitan Court of African bishops and clerics. From 16th to 20th November 1863, before a large gathering of the public in Cape Town cathedral, the case against Colenso was presented. Colenso wrote a letter protesting that Gray did not have lawful jurisdiction

583 Hinchliff (1964), pp.102, 103.

584 Parshall (2006), p.172.

for his action, and refused to attend. Instead, he was represented by a friend, a Dr Bleek. After a three-week deliberation by the bishops, the court reassembled, and Bishop Cotterill of Grahamstown presented the opening review. Colenso was found guilty on all of the nine charges of heresy laid against him, and Gray formally deposed him as Bishop of Natal. His see was formally declared vacant in May 1864.[585]

Such was the level of interest in England, that Bishop Cotterill's opinion to the court was republished as a pamphlet in London and Cambridge. This ends with the words:

> I cannot but conclude, most painful as it is to me to arrive at such a conclusion respecting one whom I continue to esteem and love, that by the false teaching proved against him, the Bishop has wholly disqualified himself,—unless he shall now openly retract and revoke this his false teaching,—for bearing rule in the Church of God, and for the cure of souls therein; and that he cannot, consistently with the laws of our Church, unless he shall thus retract his errors, retain any longer the office of Bishop of the diocese of Natal.[586]

Though Gray had stated that only the Archbishop of Canterbury could consider an appeal, Colenso took a different view and approached the civil authority of the British Privy Council, through the Crown-in-Council. He maintained that he had been appointed by the established Church of England, on the Queen's behalf, which Gray had no power to override. The Privy Council considered only the matter of Gray's legal jurisdiction, not Colenso's alleged heresy, and on these grounds declared the Cape Town trial null and void.

Though confirmed as the legal Bishop of Natal, Colenso was stuck in England, deprived of his salary by the Colonial Bishoprics Fund, and other sources of funding for his mission also dried up. Once more he was in financial difficulties, with substantial legal costs, a large family to support, and shunned by many of his former friends and colleagues. In June 1865, he completed the final, fifth, part of *Pentateuch and Joshua*, incorporating an attack on Bishop Gray. A public subscription list was opened to meet his legal expenses, and this attracted contributions from many who thought him harshly treated: among those who supported him were the novelist Anthony Trollope, the botanist Sir Joseph Hooker, the geologist Sir Charles Lyell and the liberal theologian Dean Stanley. The Colonial Bishoprics Fund was com-

---

585 Hinchliff, who provides fuller details, observes that: "A modern Anglican bishop might acquit Colenso on half the charges brought against him": Hinchliff (1964), p.135.

586 Cotterill (1864), p.45.

pelled to restore his salary in late 1866, after he had taken the bold step of returning to Natal.

In November 1865, Colenso and his family arrived in Durban to a surprisingly warm welcome. The largely autobiographical *Life of Robert Gray, Bishop of Capetown and Metropolitan of Africa* records sourly that:

> that most unfortunate person returned to the country where nothing was so much desired as his absence. He landed at D'Urban on November 6th, and was received, not indeed by the Clergy or communicants of the place, but by a mixed assembly of the indifferent or godless inhabitants, with a sprinkling of dissenters. . . .[587]

With encouragement from Longley, Gray began the process of appointing a new bishop in Natal, while Colenso regarded himself as outside Gray's African jurisdiction, a representative in Africa of the established Church of England. Charles Perry, Bishop of Melbourne, was one of the few who opposed Gray's decision.

Back at Bishopstowe, the Colenso family were isolated, cut off from such polite society as could be found in Pietermaritzburg, where Green did his best to further undermine Colenso's position. Though she still appreciated the beautiful physical setting, Mrs Colenso missed the sort of company that she enjoyed in England, and their daughters suffered likewise.

Colenso immediately intimated his intention to preach at the cathedral. Protests were delivered, and Colenso obtained a legal interdict to enter the cathedral. High drama ensued. The day before Colenso's arrival, Green locked the cathedral and spent the whole night there. In the morning, before a large crowd, both black and white, Colenso arrived and the churchwardens repeated their protest. The doors were opened when Colenso presented his interdict, and the crowd poured in to find Dean Green by the high altar. Further protests, and Bishop Gray's sentence of deposition, were read out, before Colenso could begin his service by reading the morning prayer. Soon afterwards, Bishop Gray announced that Colenso was excommunicated for continuing to preach his heresies. Nevertheless, Green and Colenso continued to share the cathedral, where Colenso attracted large congregations. Many of these sermons were published in his *Natal Sermons*.

Legal wranglings and tragicomical confrontations continued for some time, but are best passed over.[588] Finally, the first international Lambeth Conference of all the bishops of the Anglican communion took place in 1867.

---

[587] Gray (1876), v.2, p.237.

[588] See Hinchliff (1964), Ch.7; Cox (1888).

Henry Cotterill was chosen as one of its general secretaries.[589] Colenso was not invited, and attempts were made to keep discussion of him off the agenda. But Archbishop Gray proposed a successful resolution supporting the appointment of a new bishop of Natal. In January 1869, W.K. Macrorie was consecrated in Cape Town as the first, tactically renamed, "Bishop of Maritzburg". The church hierarchy in southern Africa was changing. Soon after, in 1871, Henry Cotterill gave up his bishopric of Grahamstown and returned to Britain to become the Episcopalian Bishop of Edinburgh, a post that he held for fourteen years until his death at age seventy-four.[590]

Though Colenso's salary was secure, he found it increasingly difficult to find staff for the few churches that remained loyal to him, and the missionary work at Ekukanyeni was at a virtual standstill through lack of funds. His isolation grew as his influence waned, but he still campaigned for the rights of Africans. He even returned to England in 1874 to try to reverse a blatant legal injustice against a chief, Langalibalele, who had refused to disarm his people. Colenso died on 20 June 1883, aged sixty-nine.

Let the final word go to the English Attorney-General, Lord Selborne, who had supported Gray against Colenso, and had earlier known Colenso when an examiner at Harrow. He recalled Colenso as "a man of fine presence, a famous Cambridge mathematician, with considerable force of character. These, as far as I know, were his only qualifications for the office of Bishop; though it may be added, to his praise, that, when he filled it, he was zealous for justice to the native races of South Africa."[591]

---

589 Henry Cotterill was also a general secretary of the later Lambeth conference of 1878; and secretary of a committee that considered the constitutional relations between the Church of England and its Colonial affiliates. Cazenove (1867).

590 Cotterill was appointed "coadjutor Bishop" and successor on 26 April 1871. A year later he succeeded as full Bishop on the death of the previous incumbent. He was much involved with the erection and fitting of the new St Mary's Cathedral, following a generous bequest; and he took an active part in the Royal Society of Edinburgh, to which he was elected soon after his arrival. Though he published little, in 1878 and 1880 he contributed two addresses to the Victoria Institute on the relation between science and religion. See Cazenove (1867).

591 Lord Selborne, *Memorials, Family & Personal*, v.2, p.482; quoted in Hinchliff (1964), p.161.

11.
The Growth of a Research Community

Institutions and Journals

In the mid-nineteenth century, scientific research did not have a prominent place in the British universities. A record of scholarship and of original contributions to the subject was notionally demanded of appointees to chairs; but, in practice, there were many instances of appointment of inferior candidates over better scholars, through political and personal influence. In all British universities and colleges apart from Oxford and Cambridge, the number of teaching staff was small, and most professors had heavy teaching loads. In Oxford and Cambridge, however, the professors and most college fellows had light teaching duties and ample time to devote themselves to advancing their subject if they were so inclined. But, as already noted, some professors became absentees, taking on other, usually Church, commitments that absorbed their time; and many fellows sank into a comfortable, and often indolent, life in college.

Though the education of youth was seen as an essential role of a university (at least in theory), the advancement of science was not. In advocating the establishment of a Catholic University of Ireland, John Henry (Cardinal) Newman wrote in 1852 that:

> The view taken of a university . . . is the following: that it is a place of *teaching* universal *knowledge*. This implies that its object is, on the one hand, intellectual, not moral; and on the other, that it is the diffusion and extension of knowledge rather than its advancement. If its object were scientific or philosophical discovery, I do not see why a university should have students. . . .
>
> . . . There are other institutions far more suited to act as instruments of stimulating philosophical enquiry, and extending the boundaries of knowledge, than a university. Such, for instance, are the literary and scientific "academies," which are so celebrated in Italy and France. . . . Thus the present Royal Society originated . . . in Oxford; . . . the Ashmolean and

> Architectural societies in the same seat of learning . . . the British Association, a migratory body, . . . the Antiquarian Society, the Royal Academy for the Fine Arts, and others. . . .[592]

The Catholic University headed by the Oxford-educated Newman failed after just seven years, in 1858, partly because of Irish hostility to the perceived "Englishness" of his plans, and partly because of support for the three non-denominational Queen's Colleges in Belfast, Cork and Galway. These had been founded in 1845 and—unlike the Anglican Trinity College, Dublin—admitted Protestants and Catholics alike.[593]

Newman's view of the place of research has similarities with that propounded in 1830 by Charles Babbage in his polemical *Reflections on the Decline of Science in England, and on Some of Its Causes*. This outspoken diatribe was mainly directed against the Royal Society of London, but also castigated the English universities for their neglect of mathematical science. Babbage advocated that, like French and other foreign academicians, those elected to the Royal Society should receive a *salary* to support their scientific activities. Thereby, a reinvigorated Society, and not the universities, would become the focus of research in England. Babbage's views were warmly supported by David Brewster, who was quick to propose that the Royal Society of Edinburgh should fulfill a similar role in Scotland.[594]

At this time, valuable research was still conducted by private individuals in their free time: Babbage and Brewster were just two of many who held no active university post during their most productive years.[595] The illustrious John Dalton (1766–1844), Humphry Davy (1778–1829), Michael Faraday (1791–1867) and James Prescott Joule (1818–89) had attended no university and were employed by none. Dalton taught for a time at the Unitarian Manchester Academy (later renamed New College), but he mostly made ends meet as a teacher and private tutor. Davy became a professor at the Royal Institution in London, where he gave brilliant lecture demonstrations to large audiences; and he was President of the Royal Society of London during 1820–27. Faraday became Davy's assistant, then director of the laboratory, and later the Royal Institution's professor of chemistry, while also teaching at the Royal Military Academy at Woolwich. In contrast, James Joule came from a well-to-do

592 Newman (1959), Preface.

593 In 1908, these were reorganised as Queen's University, Belfast and constituents of the National University of Ireland.

594 Babbage (1830); Brewster (1830; 1831).

595 Babbage's years as an absentee Lucasian Professor at Cambridge hardly count.

brewing family and had his own private laboratory. All four founded new sciences: Dalton developed the atomic theory of matter as well as being a noted meteorologist, Davy was a pioneering chemist, Faraday made fundamental discoveries in electricity and magnetism, and Joule demonstrated the inter-convertibility of mechanical energy and heat that established the science of thermodynamics. In astronomy, too, some of the finest observatories were owned and operated by wealthy enthusiasts, the most notable being those of Sir James South and Lord Rosse.

But the needs of science were changing, as experimental equipment became more elaborate and costly. Together with a few national institutions such as the Government-funded Royal Greenwich Observatory, it was eventually the universities, and not the scientific societies, that took on the main role of supporting research. For a time, the British Association for the Advancement of Science played an important part in financing scientific investigations. From 1834 onwards it gave grants, usually modest, for a wide range of topics. Early awards in the "Mathematics and Physics" section included support for studies of water waves, tides, the resistance of moving vessels, transmission of heat, magnetic and meteorological observations, and lunar nutation in astronomy.[596]

Earlier in the century, some individuals had directly petitioned the Government for funds. Most famously, Charles Babbage received huge sums to develop his mechanical calculating engines, which he failed to complete. Between 1823 and 1842, he received almost £17,500 from the Treasury, on favourable advice from the Royal Society, until patience finally ran out.[597] Later, Government support for experimental research was channelled formally through the Royal Society of London.

From 1828, the Royal Society had made modest grants from its Donation Fund; and from 1849 it was authorised to administer an annual Government Grant of £1000 in support of scientific research. Though William Whewell was appointed to the first Government Grant Committee, he had misgivings:

> We know the great difficulty which we had in managing undertakings supported by the money of the British Association; by no means mainly from the difficulty of procuring the money, but much more from the difficulty of avoiding the appearance and the reality of waste, caprice, partiality and jobbing. Some persons, I find, doubt whether the old practice of applying

[596] Howarth (1931) lists all grants awarded between 1834 and 1931.

[597] Swade (2000), pp.134–136.

> the screw of opinion in the scientific world to Government on each special occasion was not better than this perennial stream of bounty.[598]

Grants varied from as little as £15 to more than £200, but were mostly in the range of £50 to £100 pounds. Following a Royal Commission of 1872 chaired by the Duke of Devonshire (W. Cavendish, 2nd, 1829), the Government grant to the Royal Society for research was increased to £4000 p.a. But many in Government still opposed state funding of science: around the same time, modest requests from the British Association and the Scottish Meteorological Council were flatly refused by the Chancellor.[599]

William Thomson was just one who received Royal Society grants, to support the research work of his Glasgow laboratories. Indeed, he received so many grants over the years that in 1879 George Stokes wrote to warn him that, as he was "not in the same condition as many others as to [de]pendence upon these grants" (because of his large personal wealth by that time), some of the fellowship felt that his latest request should not be approved. Thomson replied that, though he already subsidised his laboratories from his own pocket, he would withdraw his application.[600]

For the experimental sciences, Cambridge was for long a virtual desert. Though Stokes' lecture demonstrations of optical phenomena were renowned, he had no laboratory in the University and conducted simple experiments in his own home. Probably the only other exceptions at this time were the Professor of Chemistry, James Cumming, who built electroscopes for his researches on thermoelectricity, and Robert Willis, the Professor of Natural Experimental Philosophy. In contrast, William Thomson in Glasgow had his own laboratory and another dedicated to use by his best students. And P.G. Tait in Edinburgh had a "cramped attic" where some good work was done. Early laboratories were also established at Owen's College, Manchester and at University College and King's College, London. Whereas Thomson in Glasgow and Forbes in Edinburgh devised many new pieces of experimental apparatus, from tide recorders to galvanometers, few useful scientific instruments were then developed at Cambridge.[601]

Only with the founding in 1871 of the Cavendish Laboratory and the arrival of James Clerk Maxwell did the situation in Cambridge change. And Maxwell's illustrious successors, Lord Rayleigh and J.J. Thomson, ably continued

[598] Whewell to R.I. Murchison; quoted by Hall (1984), p.148.

[599] Hall (1984), p.150; Cardwell (1972), p.126.

[600] Wilson (1990), v.1, p.xxvii.

[601] Sviedrys (1976).

the tradition of fundamental experimentation closely allied with mathematical theory. In Oxford, R.B. Clifton successfully campaigned for a physical laboratory, later named the Clarendon Laboratory.

The Cambridge Philosophical Society, founded in 1819 by the geologist Adam Sedgwick and botanist John Stevens Henslow, published an increasing number of mathematical papers in its *Transactions*. Most mathematicians who became prominent Cambridge academics served periods as office-bearers of the Society and contributed to the *Transactions*. Among its Presidents were Philpott, Stokes, Adams, Cayley and Maxwell, as well as William Hopkins.

The role of mathematicians in the Royal Society of London also increased dramatically after the death of the botanist Sir Joseph Banks. During Banks' long tenure as President of the Society from 1778 until 1820, the biological sciences had prospered; but he had a marked antipathy to mathematics, which he considered too abstruse for presentation at the Society's meetings of gentlemen scientists. The royal Duke of Sussex was a far more active and successful President during 1830–38 than many fellows had expected. Though he attended few meetings, he initiated improvements suggested by the Treasurer, John Lubbock, and by his chief adviser, George Peacock of Cambridge. In 1827, a small subcommittee had been formed to assess the suitability of papers submitted for publication. Six years later, this process was extended, so that no paper was accepted for the *Transactions* without written recommendations from two suitably qualified members of the Society's governing Council. This led to gradual improvement of the Society's *Transactions* and *Proceedings*, but the innovation was not uniformly welcomed.[602]

David Brewster, for one, was unhappy with the rejection of an optical paper in 1841. He complained that, as one of the Society's oldest members, he had "received all their Medals and have contributed about 36 Papers to their Transactions, without one of them having ever been called in question or rejected"; and the anonymous reporter had given no reason for rejecting this one. He believed that this was done because his paper "contains results and views hostile to the Undulatory Theory which seems now to be the Creed of the Society," and he believed G.B. Airy to be responsible. He sent them no more of his papers and, thirteen years later, he still railed against the Society as "governed by a Cambridge Clique who have neither a sense of feeling or of Justice."[603]

---

602 See Hall (1984), pp.26, 27, 64, 65, 68.

603 Brewster (mss.1841; 1854).

In 1854, George Gabriel Stokes took over the duties of Secretary of the Royal Society of London. Though this hindered his own scientific output, he further raised the standards of the Society's publications. With responsibility for choosing referees of submitted papers, and by his own helpful comments to authors, he was at the hub of much of the nation's research in physics and mathematics. Stokes' opinions on applications for funds must also have carried much weight. He remained Secretary of the Society for more than thirty years, until 1885, and then he served as its President during 1885–90. He was succeeded as President for the next five years by his friend William Thomson. Thomson was also active in the Royal Society of Edinburgh, being three times its President (in 1873–78, 1886–90, 1895–1907), and he is the only person to have (briefly) held both presidencies simultaneously. Also active in the Royal Society of Edinburgh were former wranglers P.G. Tait and P. Kelland.

Founded in 1837, the early *Cambridge Mathematical Journal* proved an invaluable vehicle for recent Cambridge graduates to exercise and develop their research talents. Freed from the more formal procedures for publishing in the *Proceedings* and *Transactions* of the Royal Societies of London and Edinburgh, and of the Cambridge Philosophical Society, the mostly young authors of the *Cambridge Mathematical Journal* submitted a miscellany of didactic and original material.[604] Within a few years, the research standing and geographical base of the journal grew, though not its long-term financial security. Under the editorship of William Thomson, it was renamed the *Cambridge and Dublin Mathematical Journal*; and, after a financial crisis, it was relaunched as the *Quarterly Journal of Pure and Applied Mathematics*, edited by N.M. Ferrers. It was the first British journal exclusively devoted to mathematics, and its existence gave a major boost to mathematical research in Cambridge.[605]

From its foundation in 1865, the London Mathematical Society played an important role and attracted a nationwide membership. The first president was Augustus De Morgan, and he was succeeded by J.J. Sylvester and then Arthur Cayley, all Cambridge wranglers. Its *Proceedings* were soon recognised as a leading journal for mathematical research, and it functioned as the first truly national society devoted to mathematics.

---

[604] But the first editor, D.F. Gregory, also solicited articles from his old Edinburgh teacher, William Wallace, then nearing the end of his career.

[605] See Crilly (2004a) and the following section.

Scottish and Irish Contributions

As Cambridge graduates came to dominate mathematics and natural philosophy in universities and colleges throughout Britain, so too did several Scots and Irish come to influence the mathematical and intellectual life of Cambridge itself. Kelland and Forbes (later Tait) were established in chairs in Edinburgh; W. Thomson and Blackburn (later Jack) in Glasgow; Fuller, D. Thomson and briefly Maxwell in Aberdeen; and Fischer (and later, as Principal, Forbes) in St Andrews. It was natural that they should encourage able Scots to go on to Cambridge, where a good performance in the Mathematical Tripos was likely to ensure a fellowship. Indeed, in the ten years from 1858–67, five senior wranglers had previously studied at Scottish universities (four from Aberdeen and one from Glasgow). At this time too, Scots had marked successes in the Indian Civil Service Examinations.

Quite a number of the Cambridge Scots studied at Trinity, as might be expected given its size and reputation, and several duly became fellows. Two of the earliest were Henry Parr Hamilton (9th, 1816) and James Parker (7th, 1825). Parker was previously a Glasgow graduate and he went on to become a judge and Vice-Chancellor of England. Before attending Cambridge, Hamilton was educated in Edinburgh, where his father had been professor of midwifery. He became a Trinity fellow and wrote two mathematical works for use by students: *The Principles of Analytic Geometry* (1826) and *An Analytic System of Conics* (1834) that enjoyed considerable popularity.[606] But his main calling was to the Church, as a Perpetual Curate of Great St Mary's in Cambridge during 1833–44, and as Dean of Salisbury Cathedral from 1850 until his death in 1880.

Better known as mathematicians were D.F. Gregory, A. Smith, W. Pirie, H. Blackburn and J.C. Maxwell. Later, Trinity welcomed the brothers W.D. Niven (3rd equal, 1866) and C. Niven (1st, 1867), and J. Stuart (3rd equal, 1866). All except Pirie had first studied at Scottish Universities.

James Stuart was elected in 1875 as Cambridge's first Professor of Mechanism and Applied Mechanics (in fact, engineering). He and the Nivens were early teachers of Maxwell's electromagnetic theory and did much to raise awareness in Cambridge of its importance. Stuart was also a noted educational reformer, who despite local indifference pioneered university extension lectures in cities beyond Cambridge. Encountering opposition to his

[606] These were republished in several later editions. The first of these works was commended by the Cambridge historian and mathematician W.W. Rouse Ball (1888, p.410) as "an improvement on anything then accessible to English readers."

plans for a practical engineering Tripos, he resigned his chair in 1889.[607] Stuart's successor in Cambridge was another Scot, James Alfred Ewing, an Edinburgh graduate who had previously held professorships at Tokyo and Dundee.

But it was the small college of Peterhouse that saw the greatest influx of Scots. William Thomson's father, James, had selected this college for his son because of the coaching reputation of William Hopkins, although the latter was not a fellow. In 1839, Peterhouse abolished the restrictions by (English) county of origin formerly placed on its fellowships, and Scots thereafter competed with great success. Between 1841 and 1914, from a total college intake of just over 1300 undergraduates, nearly one hundred Scots studied at Peterhouse. Most of these had already studied at university in Glasgow, Edinburgh or Aberdeen, and this relatively small percentage went on to dominate the fellowship to such an extent that it was said that, at one time, only three Peterhouse fellows came from *south* of the border. Former Peterhouse students went on to hold six Scottish chairs of mathematics or natural philosophy: Thomson, Jack, Tait, Chrystal, Fuller and Maxwell (but Maxwell was at Peterhouse for just one term, before migrating to Trinity).

Also at Peterhouse were the Canadian-born E.J. Routh, and the Irish-born but Glasgow-educated W.C. Steele and brothers W.A. and J. Porter. James Porter (9th, 1851) served as Master of Peterhouse from 1876 to 1890.[608] Like many others just mentioned, both James Porter and his predecessor Henry Wilkinson Cookson (7th, 1832, Master 1847–76) had been students of Hopkins. In 1866, Peterhouse had its first senior wrangler since E.J. Routh twelve years earlier: he was Routh's student Robert Morton, already a Glasgow graduate, and first among four Scots in the top six places. Morton became a fellow of Peterhouse and then of Christ's College, but died young in 1872.[609]

The first Scots to make their marks on Cambridge research were Duncan Gregory and Archibald Smith, who, with minor input from Samuel Greatheed, founded the *Cambridge Mathematical Journal* in 1837. Another Scot, William Pirie (5th, 1836), was a frequent early contributor.[610] And Gregory's book,

[607] Hilken (1967); Warwick (2003). In 1884, Stuart had been elected as a Liberal Member of Parliament and supported numerous reforms. Having married into the wealthy Colman family, he for a time managed the famous mustard firm, following his father-in-law's sudden death.

[608] He was also a keen supporter of cricket, serving as Treasurer of the Cambridge University Cricket Club during 1884–1900.

[609] See Pattenden (2002).

[610] The publishers were also Scots, the Cambridge-based firm of Macmillans. The authors of early papers were indicated only by pseudonyms, often single Greek letters; but most were later identified.

Examples of the Processes of the Differential and Integral Calculus (Gregory 1841), provided a valuable compendium of analytical results, culled mainly from continental books and journals. But Gregory had to return to his Edinburgh home when his health broke down in late 1842, and he struggled to edit the *Cambridge Mathematical Journal* from a distance until his death in 1844, at the age of just thirty. His Trinity friends Robert Leslie Ellis and William Walton took over in his place.[611]

The sixteen-year-old William Thomson had contributed an anonymous article to the *Cambridge Mathematical Journal* in 1841, just before becoming a first-year undergraduate. Three years later, Thomson was assisting Ellis and Arthur Cayley with editing the journal, and in 1845 he took over most of the duties. He enlisted George Stokes to write articles, and regular contributions came from Cayley and James Joseph Sylvester. With ambitions to transform it into a major national journal, Thomson negotiated with Irish mathematicians, and the journal was eventually renamed the *Cambridge and Dublin Mathematical Journal*. An immediate result was the publication of a three-part paper, mainly on quaternions, by the leading Irish mathematician William Rowan Hamilton.[612]

On returning to Glasgow as professor, Thomson had much else to do, and he gradually tired of running the journal. By 1852, it was in financial difficulties, and G.G. Stokes, not usually a man to shirk responsibility, turned down Thomson's invitation to take it over. Instead, the recently graduated Norman Macleod Ferrers (1st, 1851) became the next editor in 1853.[613] His immediate priority was to curb the verbosity and impenetrable style of the enthusiastic and productive J.J. Sylvester, whose papers, though mathematically worthwhile, were occupying too much space in the journal for most readers' taste. Under Ferrers' guidance, the ailing journal was transformed into the successful *Quarterly Journal of Pure and Applied Mathematics* (1855–1927); and Sylvester later joined him as a joint editor. The journal was later incorporated into the *Quarterly Journal of Mathematics* which still continues publication.

[611] Walton was a respected private tutor and author of several textbooks, in later life an eccentric with a long white beard who wore a "Scotch bonnet & Plaid" though apparently not a Scot: Venn & Venn (1940). He edited the collected papers of both Gregory and Ellis: the ailing Ellis wrote a biographical memoir of Gregory for the former volume, but this did not appear until after his own death.

[612] Hamilton (1846). A comprehensive account of the history and context of the journal is given by Crilly (2004a).

[613] Despite his middle name, Ferrers was not born a Scot, but his mother was a Macleod from the Isle of Harris.

Though Thomson had left Cambridge for Glasgow, he was a fairly regular visitor, and his lifelong scientific correspondence with G.G. Stokes touched on most of the major developments of physics and mathematics of their day. In the most productive scientific association of the nineteenth century, the two discussed their opinions, speculations, and their new experimental and mathematical results.[614]

The main Irish contributors to Cambridge research were Robert Murphy, Matthew O'Brien and, most importantly, G.G. Stokes. The appointment as professors of Stokes in 1849, John Couch Adams in 1859, and Arthur Cayley in 1863 recognised three outstanding figures and fostered a research ethos that had previously been sporadic at best. They were supported by a new generation of active college fellows and tutors, notably Norman Ferrers, William Besant, Isaac Todhunter, Percival Frost, Joseph Wolstenholme and Edward Routh, all of whom published some original research; and also Stephen Parkinson, who did no research but wrote two popular textbooks and was a highly regarded teacher and lecturer. But there were still no "research groups" in the modern sense: for the most part, individuals worked alone without regular interaction with one another.

The growth of experimental physical science had to await the founding by the seventh Duke of Devonshire of the Cavendish Laboratory, and the appointment in 1871 of James Clerk Maxwell as the first Cavendish Professor of Experimental Physics. Though now remembered for his fundamental *theoretical* contributions to physics, Maxwell initiated a major programme of electrical experiments to confirm fundamental laws and to establish a basic system of units of measurement. Much of this work was done under his direction by his students and assistants George Chrystal, William Garnett, Charles Hockin and Arthur Schuster.

Maxwell was conscious that many in Cambridge remained suspicious of experimental science, and he was anxious not to distract potential high wranglers to the detriment of their mathematical studies. Soon after arriving as professor, he wrote to J.W. Strutt (1st, 1865; later Lord Rayleigh and Maxwell's successor) that:

> it will need a good deal of effort to make Exp. Physics bite into our University system which is so continuous and complete without it. . . . If we succeed too well, and corrupt the minds of youth, till they observe vibrations and deflexions and become Senior Op[time]s instead of

614 Wilson (1987; 1990).

> Wranglers, we may bring the whole University and all the parents about our ears.[615]

Maxwell's sympathetic approach bore fruit: his lectures on heat, electricity and magnetism firmly established these subjects within the Mathematical Tripos, and he welcomed recent graduates to work in his laboratory.

After Maxwell's untimely death in 1879 at the age of forty-eight, it was through the expository lectures of W.D. and C. Niven and of James Stuart that Maxwell's theories became established in the Cambridge syllabuses of the Mathematical and Natural Sciences Triposes.[616] Maxwell's achievements in the kinetic theory of gases and in electricity and magnetism were also propounded in quite advanced expository works by H.W. Watson (2nd, 1850) and S.H. Burbury (15th, 1854 and 2nd Classic). Maxwell's own *A Treatise on Electricity and Magnetism* had seemed impenetrable to many: without these lecture courses and textbooks by his followers, appreciation of Maxwell in Cambridge would have been far less rapid.[617]

In 1875, Edinburgh-trained James Dewar was elected Jacksonian professor of natural experimental philosophy, thereby becoming Cambridge's third Scottish professor in the physical sciences, with Maxwell and Stuart. There, he collaborated with the professor of chemistry, G.D. Liveing, most notably on spectroscopy and cryogenics. Later Scottish-born professors were James Ewing, who succeeded Stuart; and Andrew Russell Forsyth, who succeeded Cayley. Ewing had studied in Edinburgh with P.G. Tait and Fleeming Jenkin, while Forsyth was the Cambridge senior wrangler of 1881, having previously studied at the Liverpool Collegiate Institution.

Table D lists, by countries of birth, those top wranglers for 1828–56 who made significant contributions to research and scholarship in mathematics or physical science. (To these, one might add the observational astronomers Robert Main and Charles Pritchard, both English; and the Irish W.C. Steele, who died too young to fulfill his early promise.) Though Scots and Irish formed a very small percentage of the total student population, they gained more than ten percent of the top three Tripos places in the years mentioned;

---

[615] Maxwell to J.W. Strutt, March 1871; quoted in Harman (1998), p.60.

[616] W.D. Niven had been a particularly close friend of Maxwell, and it was he who wound up Maxwell's scientific affairs. He prepared for the press the second edition of Maxwell's *Treatise* that Maxwell had partly revised; and he wrote an appreciative biography that prefaced Maxwell's two-volume *Scientific Papers*.

[617] Watson (1876); Watson & Burbury (1885; 1889); Maxwell (1873). See also Hunt (1991); Harman (1998); Warwick (2003).

Table D. Wranglers 1828–1856, by region of birth, who became notable scholars and researchers in mathematics or physics

England	Scotland & Ireland	Other
(S. Earnshaw)	R. Murphy	E.J. Routh (Canada)
J.H. Pratt	A. Smith	
P. Kelland	D.F. Gregory	
(W. Walton)	M. O'Brien	
J.J. Sylvester	G.G. Stokes	
G. Green	W. Thomson	
P. Frost	P.G. Tait	
R.L. Ellis	J.C. Maxwell	
A. Cayley		
J.C. Adams		
F. Bashforth		
I. Todhunter		
(W.H. Besant)		
J. Wolstenholme		
H.W. Watson		
N.M. Ferrers		

All except those in parentheses are included in the *Oxford Dictionary of National Biography*.

and the table shows that their later research contributions are even more disproportionate. The reasons why they outshone so many of their English-born contemporaries require some disentangling.

A cursory examination reveals that most of the Scots and Irish had previously studied at another university before enrolling at Cambridge: Smith, Thomson and Steele at Glasgow University; Gregory, Tait and Maxwell at Edinburgh; and O'Brien at Trinity College, Dublin. They would have covered a good part of the Cambridge mathematical syllabus before arriving. Similarly, at Bristol College, though not a university, Stokes received excellent mathematical instruction. Only Stokes and Murphy went straight to Cambridge, and Murphy did so only because he had first been rejected by Trinity College, Dublin.

Few of these Scots and Irish would have regarded their college fellowships as jobs for life. With the possible exception of the devout Stokes, they would not have considered taking orders in the Anglican Church, and so could hold college posts only for a few years. Many may have wished to return home if they could find suitable employment, and may therefore have felt more pressure to gain credentials that would secure a professorship at another university. Importantly, most arrived in Cambridge with academic aspirations and with intellectual and political opinions already well-formed, following their earlier academic successes elsewhere.

Politically, many of the Scots were inclined towards the Whigs or radicals, whereas the majority of Cambridge students were of Tory persuasion. And most Scots would have had at least second-hand experience of the industrial, entrepreneurial and mercantile activity that was transforming the nation, but which was far less evident in the English shires. These factors, too, may have encouraged a progressive outlook that valued scientific research.

Another factor may have been a certain clannishness of the Scots and Irish at Cambridge, who would have thought of themselves, and been thought by others, as in some ways different from their English peers.[618] Gregory and Smith were friends and collaborators, later joined by Thomson; the lifelong interaction of Thomson and Stokes is legendary; Tait collaborated with Steele and Thomson, and he remained a lifelong friend of Maxwell. Slightly later, fellow-Scots seem to have been particularly keen to work with Maxwell, among them Chrystal, the Niven brothers and James Stuart. Though a sense of national identity may have played a role, it also seems likely that their previous Scottish university education fired their enthusiasms for both experimental work and speculative natural philosophy.

Because most English students proceeded straight from school to university, they were perhaps more likely to adopt unquestioningly the gentlemanly attitudes that the public schools and Cambridge colleges traditionally fostered. But some English students first studied for a time at the University of London, and it seems significant that these include several listed in Table D: Pratt, Sylvester (briefly), Todhunter and the Canadian-born Routh were all taught by the talented Augustus De Morgan at University College; whereas Cayley and Watson spent some time at King's College, London.

The school education of those in Table D is also revealing. Remarkably few attended prestigious public schools: only Kelland (Sherborne) and Ferrers (Eton) did so. Among the remainder, Green and Murphy were largely self-educated; R.L. Ellis was taught exclusively by private tutors; Thomson was educated by his father; Adams attended a small private school run by a cousin; Bashforth attended Doncaster Grammar School, and Sylvester the Royal Institution School in Liverpool; Wolstenholme attended Wesley College in Sheffield; and Tait and Maxwell were at Edinburgh Academy. It is also true

618 Recall the pejorative remarks about Scots by J.M.W. Wright, quoted in Chapter 2.

that very few other high wranglers *absent* from the above Table received a conventional upper-class education at a top English public school: of the Scots who did so, the senior wrangler A. Ellice attended Harrow for three years, and the brothers Hugh and Colin Blackburn, respectively fifth and eighth wranglers, attended Eton.[619]

Several conclusions suggest themselves. First, the top public schools seem to have done a poor job in preparing their students for university and in motivating them to serious study once they got there. Second, the preference of even the most able English-born students was not usually for science *per se.* Unattracted by poorly paid and overworked professorships at institutions less privileged than Cambridge, they instead sought careers in the Church and the law, or the comfortable life of a Cambridge fellow. Third, despite William Hopkins' efforts in this direction, a Cambridge education *alone* seems not to have motivated many students to undertake original scientific and mathematical research. Hopkins taught many in the above Table, but also many other high wranglers who did not embark on research. Nearly all those who later succeeded in research combined their rigorous Tripos training with earlier and broader study elsewhere. The *combination* of breadth of outlook and technical facility was the best platform for success.

To summarise: it is undeniable that Cambridge exerted a strong influence on other institutions through their employment of Cambridge wranglers as professors of mathematics and natural philosophy. Throughout the country, and in some cases overseas, academic standards in these subjects were raised thereby. But the trade was not one-way: these professors maintained contacts with Cambridge, and urged the best of their students to follow in their footsteps. Cambridge benefited greatly from this influx of well-trained talent, especially from Scotland and to a lesser extent from Ireland, and this led its research to new heights.

[619] Dauglish & Stephenson (1911); Venn & Venn (1940).

12.
Achievements in the Mathematical Sciences

The Mathematical Sciences Before 1830

By the 1830s, the main areas to which mathematics had already been successfully applied were mechanics, planetary astronomy, hydrostatics and hydrodynamics, and optics. All of these were prominently represented in the Tripos; and so it was these topics that mainly attracted the interest of the wranglers. To set the scene (and at great risk of oversimplification), the evolution of the mathematical sciences before 1830 is first summarised; then many of the major advances made during the period 1830–80 are reviewed, with emphasis on the work of our wranglers.[620]

Mechanics is the study of the equilibrium and motion of bodies under applied forces. (In the mid-twentieth century, this was renamed "classical mechanics" to distinguish it from the new fields of statistical, relativistic, and quantum mechanics.) It naturally subdivides into *statics* and *dynamics*. Statics is the study of mechanical systems in equilibrium under applied forces, and dynamics concerns the motion of bodies induced by applied forces.

Frequently, a solid body can be regarded as a mass concentrated at a single moving point, to which Newton's laws are directly applicable. Calculation of the motion of such "point particles", acted on by a constant gravitational force, adequately describes the paths of solid projectiles (including objects such as cannon-balls). Isaac Newton himself improved on this by incorporating a drag force to model air resistance. Numerical tables of such trajectories were long used in warfare for range-finding of artillery. Other early theoretical developments included the laws of impact of colliding bodies, and the motion of pendulums under gravity: the latter crucial to the development of accurate clocks, and for detecting local variations of the force of gravity itself.

---

[620] Few original references are given in this section, as much of the material is summarised elsewhere: see e.g. Grattan-Guinness (1994) and references therein.

On larger scales, Newton's inverse-square law of gravitation replaces the assumption of a constant gravitational force that is adequate for motion near the Earth's surface. It was Newton who first calculated correctly the motion of a planetary body around a much more massive star such as the Sun. The orbit turned out to be a conic section (ellipse, parabola or hyperbola): a fortunate outcome, for the main properties of these curves had been known since antiquity. Only the ellipses give periodic orbits. All the planets known in Newton's day follow elliptical orbits that are almost circular; but the elliptical orbits of returning comets, such as Halley's comet, are extremely elongated. The latter provided good evidence for the continuing accuracy of the inverse-square law, even at great distances from the Sun.

Given a solid body of known dimensions, it is possible to calculate the net gravitational force exerted on that body by another known mass, by summing (or integrating, using calculus) all the contributions from its constituent parts. Likewise, one can calculate the gravitational force exerted *by* such a solid body on an arbitrary "point particle" of specified mass. In this way, the finite size of bodies can be taken into account.

When a solid body rotates, there are further complications, successfully solved in the mid-eighteenth century by the great Swiss mathematician Leonhard Euler. In the absence of external forces, a non-symmetrical solid body can rotate uniformly only about three possible axes (called "principal axes") fixed in the body, with directions at right-angles to one another. Any other rotation in the absence of external forces exhibits a periodic wobbling or tumbling which can be calculated. The rotational motion of a solid body under externally applied couples can also be found. Early nineteenth-century applications of mechanics to astronomy included calculation of such small periodic variations in the motion of the Earth, known as "precession" and "nutation", under the influence of perturbations of the net gravitational force exerted by the combined action of the Sun and Moon.

The geometers of ancient Greece, especially Archimedes, made considerable advances in statics, finding centres of mass and positions of equilibrium of various solid bodies. Later, calculation of the forces within structures, such as connected frameworks of beams and joists, proved of great importance in architecture and building construction, when allied with empirical rules regarding the strength of materials. At the end of the seventeenth century, Jakob Bernoulli devised a theory for the elastic deflection of blades and plates under applied forces. Its extension by Euler in 1744 marked the beginning of the theory of *elasticity*: this encompasses the bending of beams and the distortion of deformable solids by applied forces and couples. Early applications to the elastic vibrations of rods and plates, and to wave motion of stretched strings and membranes, helped to explain the generation of musical sounds by musical instruments. The theory of elasticity later developed in parallel with those of viscous fluid mechanics and of optics, with which it has very close mathematical similarities. In due course, this led to the development of seismology, with further important applications.

The mathematical study of *hydrostatics*, the equilibrium of fluids and of floating bodies under gravity, originated with Archimedes in the third century BC. His theoretical insights allowed the solution of several practical problems: these ranged from determining the proportion of gold to base metal in a king's crown, to estimating the stability or instability of laden ships. Much later, when allied with Newton's inverse-square law of gravitation, hydrostatics was extended to calculate the possible shapes of self-gravitating, rotating fluid bodies such as the Earth itself (if supposed liquid). Following Newton's lead, the Frenchman Louis Clairaut, the Scot Colin Maclaurin, and later Pierre Laplace and James Ivory, developed models for the "figure of the Earth" and of other rotating heavenly bodies. These confirmed Newton's view that the shape of the Earth must be an oblate spheroid (i.e. an ellipsoid with rotational symmetry, flattened at the poles).

The study of *fluid mechanics* lagged behind that of the mechanics of rigid bodies. The general governing equations of non-viscous fluid motion had been determined around 1755 by Leonhard Euler, following earlier work by two other Swiss, the father and son Johann and Daniel Bernoulli, and by Jean d'Alembert in France. But, apart from a few cases of limited interest, these equations resisted all attempts at solution. For a long time, useful applications mostly relied on an earlier approximate theory of Daniel Bernoulli, and on still-earlier empirical laws that gave acceptable estimates of hydraulic flows through pipes and conduits.

But one notable exception was the theory of wave motion, based on Euler's equations. This was first developed in the late eighteenth century by Laplace and Lagrange in France. They gave correct theories of waves of small amplitude in shallow water, and (in the over-idealised situation of a uniform shallow ocean covering all the Earth's surface) of tides on the rotating Earth, forced by the gravitation pull of Sun and Moon. Later French work on water waves by Cauchy and Poisson also preceded the major theoretical advances made in Britain after 1830.

The study of *optics*, like that of mechanics, has its origins in antiquity. Concave mirrors were known to focus the Sun's rays and produce burning; and the apparent reduction in depth of submerged objects, caused by refraction, was noted. Spectacles had been used for correcting vision from as early as the fourteenth century. In the early seventeenth century, Dutch and Italian scholars, including Galileo, developed the first successful telescopes. In 1621, the Dutchman Willebrord Snel first proposed the law of refraction, a modernised form of which is named "Snell's Law". This describes how light rays are deflected, or refracted, at an interface between different transparent media, such as air/water or air/glass. In connection with astronomy, Johannes Kepler described both spherical and chromatic aberration of lenses. These were troublesome defects of refracting telescopes, long believed to be unavoidable; but in 1758 the London optician John Dollond exploited theoretical ideas of Leonhard Euler and brilliantly eliminated the aberration by using composite lenses, made of two pieces of glass with differing densities.

Robert Hooke achieved popular fame for his *Micrographia* of 1665, mainly because of his minutely detailed drawings of tiny objects (most notably a flea) seen through his microscope. He also described diffraction, and suggested that light consists of vibrations. In the same year, Francesco Grimaldi claimed that light propagates like waves; and Christiaan Huyghens, in his *Traité de la Lumière* of 1690, also advanced the wave theory of light, proposing what is now called "Huyghens' Principle". This is a geometrical method for calculating the successive positions of curved wave fronts as they propagate away from small apertures. Huyghens also applied this method to explain double refraction when light passes through crystals of Iceland spar or calcite.

Isaac Newton began to develop his own theory of light around 1668, and it was finally published in his *Opticks* of 1704. By means of a glass prism, he had split white light into its constituent "rainbow" spectrum. This led him to propose that rays of each colour retained their own identities, with slightly different properties. Though he did not offer a firm explanation of the nature of rays, he suggested that they might be composed of tiny, rapidly moving "corpuscles", streaming from their bright source. This corpuscular theory, centred on rays, conflicted with the wave theories of Hooke and of Huyghens.

Around 1800, the Englishman Thomas Young studied interference and diffraction, and showed these to be consistent with the wave theory of light.[621] Not long after, important experimental and theoretical work on polarisation was conducted in France by Jean-Baptiste Biot, François Arago, and Augustin Fresnel. By 1821, Fresnel's observations convinced him that light consisted of wave motion that had no component in the direction of propagation: that is to say, light consists of *transverse* waves. Also in the 1820s, improved theories of the gradual refractive bending of light on passing through the Earth's atmosphere (because of its changing density) were given by Friedrich Wilhelm Bessell and James Ivory.

---

[621] Thomas Young (1773–1829) was brought up as a Quaker, but later joined the Church of England. He studied medicine at Edinburgh, Göttingen and Cambridge. He was a remarkable linguist and polymath, a prolific writer, and an outstanding physicist; but his mathematics, though serviceable, was crude and old-fashioned.

Many of these scientific advances were crucial for astronomy. Bigger and better telescopes enabled far more heavenly objects to be seen and recorded; spherical geometry and trigonometry allowed the mapping of the sky; improved theoretical knowledge and high levels of craftsmanship enabled construction of aberration-free lenses, larger mirrors, and ever more accurate clocks; and there was new knowledge of the various "wobbles" of the Earth's motion, and of the effects of atmospheric refraction. All these came together in establishing the true position of a star, or planetary orbit, from its apparent one observed by telescope through the variable atmosphere of an orbiting, rotating, and slightly wobbling Earth.

Heat, *electricity* and *magnetism* were topics little studied at Cambridge before the 1830s, for their theories were still speculative and definitive experiments had yet to be made. Early attempts at a theory of heat had some partial success (such as "Newton's law of cooling"); in Glasgow in the 1760s, James Watt's and Joseph Black's studies of the steam engine led to their discovery of the latent heat of steam; and worthwhile experiments on heat and cold were subsequently conducted by John Leslie of Edinburgh and by others. A correct mathematical description of heat conduction (or diffusion) was first achieved by Joseph Fourier in his *Théorie Analytique de la Chaleur* of 1822.

A theoretical understanding of electricity and magnetism had not developed far by the early nineteenth century, although some phenomena had long been known: magnets were used in navigational compasses, and both the power of lightning and the attractive force of electrified amber and ebony were familiar. William Gilbert's *De Magnete* of 1600 was a pioneering publication, but no important work on magnetism was to follow until the nineteenth century.

Negative and positive electrical charges were distinguished in 1732–33 by Charles Dufay, and a "two-fluid" theory (supported by Benjamin Franklin) was proposed to explain the effects. In England, Joseph Priestley (1733–1804) and Henry Cavendish (1731–1810) made significant experimental discoveries in electrostatics, and Cavendish developed a "one-fluid" theory to try to explain the nature of electrical forces. But much of the eccentric Cavendish's work remained unpublished until long after his death. (Cavendish's laboratory notes, edited by James Clerk Maxwell, were eventually published in 1879.) In 1785–87, Charles Coulomb made the important discovery[622] that the force associated with an electrical charge varies as the inverse-square of distance from the source, in just the same way as does the gravitational force. The force associated with a magnetic pole was later found to vary similarly.

[622] Or at least the assertion, based on very limited experimental evidence: see Falconer (2004).

The discovery that an inverse-square law applied both to electrostatics and to magnetism soon led to mathematical treatment by Lagrange, Laplace, Poisson and others, who exploited the known techniques for gravitation. As in gravitation, their theories of electro- and magneto-statics involved finding a mathematical function, called the "potential", associated with each chosen distribution of electric charges or magnetic poles. From this potential function, the force on an arbitrarily situated, electrically charged particle, or magnetic pole, could readily be calculated.

The early electrostatic theories ignored electric currents in conductors, which had first been discovered by Luigi Galvani in the 1790s; and the first metal and cardboard batteries (known as "Voltaic piles") for their production were made by Alessandro Volta in 1799. In England, Sir Humphry Davy's interest in these batteries led him, from around 1806, to study the relationship between electricity and chemical reactions. Connections between electricity and magnetism were gradually discovered, and early but incomplete attempts at electromagnetic theories were developed by Hans Oersted and André Marie Ampère around 1820.

Few of the above-mentioned advances could have been possible but for the development of new mathematical methods. Until the early seventeenth century, virtually the only forms of mathematics were *Euclidean geometry*, much as developed by Euclid in the third century BC, and some fairly cumbersome *algebra*, *trigonometry* and *arithmetic*. Arithmetic was enhanced by John Napier's (1614) and Henry Briggs' (1624) logarithms; and Descartes' *Géométrie* of 1637 and contemporaneous work of Pierre Fermat fruitfully introduced algebra into geometry in what is now called *Cartesian* or *coordinate geometry*. Further early-seventeenth century work by Cavalieri, Fermat, Roberval, Kepler and others resulted in a theory of "indivisibles" that streamlined the methods first used by Archimedes to calculate arc-lengths, areas and volumes. Meanwhile, new methods of finding tangents to curves were developed by Fermat, Slusius and Newton's Cambridge predecessor, Isaac Barrow. In the 1660s and 1670s, these theories were brilliantly brought together in Isaac Newton's "theory of fluxions", and in Gottfried Wilhelm Leibniz's slightly later differential and integral calculus. Though Newton's 1687 *Philosophiae Naturalis Principia Mathematica* (*Principia* for short) is cast mainly in the language of traditional Euclidean geometry, his fluxional methods are not far below the surface. And it was these methods and those of Leibniz that held the key to the future.[623]

[623] See, e.g. Edwards (1979).

As part of his theory of fluxions, Newton had expertly employed infinite series to represent unknown quantities, such as the arc lengths of curves and the areas enclosed by them. So too had the Scot James Gregory. This topic was later pursued in England and Scotland by Brooke Taylor, Colin Maclaurin and James Stirling; and, on the continent, by the Bernoulli brothers and the prolifically brilliant Leonhard Euler.

Application of Newton's laws of motion gave rise to many important advances, such as those by the brothers Jakob and Johann Bernoulli. For example, they devised a way of calculating the curved shape of a smooth wire, connecting two given points, down which a mass would slide under gravity in the shortest possible time. This, the "brachistochrone problem", was of a new, inverse sort: it involved finding a curve that satisfied a given mechanical property, rather than determining the behaviour of a particle constrained to follow a given curved path or projected as a missile. These ideas were later extended by Euler and Jean Lagrange into the widely applicable *calculus of variations*.

It has wrongly been suggested that all the later developments of mechanics and fluid mechanics are merely routine extensions of Newton's *Principia*, in which the laws of motion of a moving particle were first formulated. In fact, even the use of Newton's laws to find the motion of rotating rigid solids required a novel viewpoint. And the development of theories for vibrating strings and membranes, and for moving (non-viscous) fluid bodies, required a completely new approach, because these involve a *continuum* of moving particles rather than just a few discrete point masses. These theories, first begun by father and son Johann and Daniel Bernoulli and by Jean d'Alembert, were definitively established by Leonhard Euler. At their heart are *partial differential equations* describing the connection between displacement, velocity, acceleration and applied forces (including pressure forces) at each point of space, rather than following individual particles as they move. (Though a "particle-following" formulation is also possible, it is usually far more cumbersome to apply. For fluids, this is misleadingly referred to as a "Lagrangian formulation", in contrast with the more usual "Eulerian" one. But Euler deserves priority for both versions.)

Also attributable to Euler is much of the now-standard notation of mathematical analysis: his many treatises are characterised by both originality and clarity of expression—an all-too-rare combination. As techniques developed for solving both ordinary and partial differential equations, the armoury of mathematicians became ever more powerful. By the end of the eighteenth century, the main centre of activity was in France, and mostly in Paris, where Laplace, Lagrange, Legendre, Lacroix, Fourier, Poisson and Cauchy were the leading lights of the highly mathematical new "physique". The belated introduction of their methods into Britain has already been discussed in Chapter 4, pp.58–63.

The origins of probability and statistics, and their practical applications, go back to the posthumously published *Ars Conjectandi* (1713) of Jakob Bernoulli and to Abraham De Moivre's *Doctrine of Chances* (1718) and his later publications. Though both mainly considered applications of mathematics to games of chance (in which the binomial series plays an important role in determining permutations and combinations), they were conscious of wider possible applications to the calculation of annuities, to insurance, and to other still-undeveloped social sciences. But it was the application to astronomical measurements by Adrien Marie Legendre that brought further crucial developments. In 1805, Legendre published a slim volume entitled *Nouvelles Méthodes pour la Détermination des Orbites des Comètes*: in an Appendix, he set out his *method of least squares*, which was to remain a standard statistical technique from that day to this. This method improved on a previous one, first used by the astronomer Tobias Meyer in the late 1740s, for calculating the probable orbit of a heavenly body from a surfeit of numerical data that inevitably contained random observational errors. In the method of least squares, the probable path was that which minimised the sum of the squares of all the observational discrepancies from it. The need for such methods had been emphasised in 1801, when the minor planet Ceres had been found and then lost again after a few weeks: Carl Friedrich Gauss, who had independently devised the method of least squares, applied it to predict correctly the new position.

Soon, Gauss and Pierre Simon Laplace supplied strong theoretical support for the method of least squares, showing that it gave the true orbit when the observations were scattered with probability in accordance with a *normal distribution*. This distribution is expressed as a class of symmetric bell-shaped mathematical functions: the greatest numbers of observations occur where the error is small, and there are ever fewer as the error increases. This normal distribution turns out to be connected with the binomial distribution of a finite number of objects that arises in probability theory: see Figure 20. This Figure, first published by A. Quetelet in 1846, shows the expected distribution of possible outcomes when 999 balls are drawn randomly, with replacement, from an urn containing an equal number of black and white balls. Its form is close to the continuous bell-shaped normal distribution. (The two outcomes of greatest frequency have 499 balls of one colour and 500 of the other. The extremes at right and left show the frequencies of occurrence of 550 or 450 balls of one colour; frequencies of occurrence of numbers outside this range are too small to be shown.)

Later studies of many large sets of data, in wide-ranging contexts, showed the normal distribution to be almost universal, whenever the things measured were of the same sort and subject to random variations. For instance,

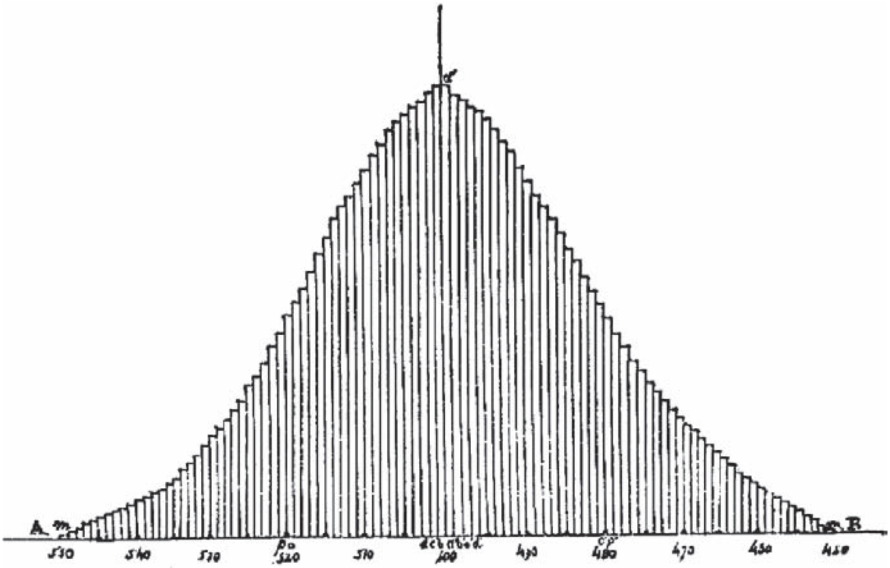


Figure 20. A symmetric binomial distribution with 999 trials. As the number of trials increases, the shape approaches ever closer to the normal distribution. In the kinetic theory of gases, the normal distribution is called the “Maxwellian distribution”. [From Stigler (1986) p.209, after Quetelet.]

in 1827 Alexis Bouvard found that the average barometric pressure for a given month of each year was distributed normally about the overall average for that month taken over many years; and Adolphe Quetelet examined a wealth of social statistics, from the height and weight of French army conscripts to the yearly proportion of convictions to accusations in the criminal courts. This work was later to be extended by British researchers.[624]

The Mathematical Sciences, 1830–1880

Mechanics, Planetary Astronomy and Fluid Mechanics

The “figure of the Earth”, its precession and nutation under small variations of the net gravitational force of Sun and Moon, and the theory of perturbations of the Moon’s orbit all featured prominently in George Airy’s

[624] A comprehensive historical survey of statistics is given by Stigler (1986).

Mathematical Tracts of 1826. Airy's work did much to establish Cambridge's interest, through the Tripos and Smith's Prize examinations, in applications of mathematics to astronomy. Also, his Cambridge lectures on mechanics, optics, hydrostatics and "pneumatics" (theory of gases) during 1827–28 promoted the study of these other fields. William Hopkins' 1839–42 research on precession and nutation of a part-solid and part-liquid Earth closely followed Airy's methods.[625]

In 1834, Carl Jacobi and Joseph Liouville made the unexpected mathematical discovery that a rotating self-gravitating mass of fluid could assume *non-symmetrical* shapes of equilibrium. Though still ellipsoidal, these could resemble a slightly squashed rugby ball, a nearly flat, not-quite-symmetric discus, or a long thin shape like a squashed cigar.[626] In 1882, William Thomson showed that many of these solutions are unstable if not artificially constrained to be ellipsoidal—quite literally, they go pear-shaped. (A more complete account was given soon after by Henri Poincaré in 1885.) And Thomson speculated that the moons of planets, and double stars, might have resulted in the distant past from instability of the cigar-shaped solutions. In a later study influenced by Thomson, George H. Darwin (2nd, 1868), a son of Charles Darwin, suggested that the Moon had separated from the Earth in this way: subsequently, tidal friction had slowed the Earth's rotational period from perhaps as little as two hours to its present value, while the distance of the Moon gradually increased.

Characteristically, Thomson's friend George Stokes avoided such grand speculations; but, in an influential contribution to the new field of geodesy, in 1849 he calculated the small variations in the force of gravity observed in the neighbourhood of land masses such as mountains. This led to later mathematical models by Pratt and Airy for the composition of the Earth's crust near mountain ranges: see Chapter 10, pp.255, 256.

In 1845, Lord Rosse had constructed the world's largest telescope at Parsonstown in Ireland, and made the first observations of spiral nebulae. Astronomy was by then a worldwide activity, combining sophisticated mathematics and refined experimental techniques to ask and answer many new questions and to make many new discoveries. In theoretical astronomy, John Couch Adams (1st, 1843) and Urbain Le Verrier spectacularly predicted the existence and location of a new planet, a story already told in Chapter 8. And, later, Adams refined and corrected the theory of lunar perturbations by painstaking calculations: this is an example of the "three-body problem",

[625] These were mentioned in Chapter 5, pp.121, 122.

[626] Lützen (1984).

which can only be solved approximately. Other astronomical work at this time included the discovery of many comets and minor planets (or asteroids) and calculation of their orbits, and also the preparation of new, more-accurate and more-complete star catalogues. More than two hundred comets were discovered during the nineteenth century as a whole. Up to 1848, only eight minor planets, or asteroids, were known, but this number had increased to 432 by 1897. A striking theoretical contribution by James Clerk Maxwell in 1857 showed that Saturn's rings could not be solid or liquid, but must be composed of a huge number of small solid bodies.

The first estimates of the distance of stars were made by measuring the tiny angle of parallax associated with the Earth's annual orbit round the sun; and such measurements were later facilitated by the photographic methods of Charles Pritchard at Oxford. Also at Oxford, and earlier at the Royal Observatory, Greenwich, Robert Main made many worthy contributions to observational astronomy. And Alexander Herschel's observations of meteors helped to establish their connection with comets. Developments in photography aided the construction of star catalogues and the beginnings of spectral analysis, whereby so much has since been discovered about the chemical composition of distant bodies.[627]

Despite the insights they provided, the tidal theory of Laplace, and later studies by Airy, were insufficient to describe the actual tides observed at coasts and harbours. Because the latter were of great importance to the Admiralty and to shipping generally, John Lubbock (1st Senior Optime, 1825) and William Whewell undertook extensive observations and data analysis of the tides around Britain, with financial support from the British Association for the Advancement of Science. Early tide records, restricted to measurements of just high and low tides, were replaced by automated continuous recordings. In the 1870s, these recorders were themselves much refined by William Thomson's "harmonic analyser", a tide-recording device that separately recorded each wavelike component with different frequency. This, the first automatic "Fourier analyser", enabled tide prediction from a far shorter time-record than had previously been possible. These tidal computations were notably continued by G.H. Darwin and others.[628]

During 1838–47, the Cambridge wranglers Green, Kelland, Airy, Earnshaw and Stokes all contributed to the theory of water waves. Later, William Thomson, Lord Rayleigh and W.J.M. Rankine in Britain, and J.V. Boussinesq

---

627 Berry (1898).

628 Thomson & Tait (1879), v.1, pp.479–482, 505–508; Cartwright (1999), pp.97–109; Smith & Wise (1989), pp.370–371.

in France, made further substantial advances. These included Thomson's masterly approximate analyses of the wave patterns generated by moving ships (see Figure 21), and by sudden localised impulses; Thomson's and Rayleigh's studies of short waves affected by surface tension; and Boussinesq's and Rayleigh's work on solitary waves. Lord Rayleigh's *Theory of Sound* and related papers also treated waves of another sort: those caused by compression and rarefaction of air.[629]

The full equations of *viscous* fluid dynamics were first derived by Navier, Cauchy and Poisson in France during the 1820s; then, under improved hypotheses, by Saint-Venant in 1837 and G.G. Stokes in 1845.[630] These, the *Navier-Stokes equations*, contain more terms than do Euler's non-viscous equations—and even the latter were then regarded by many as intractable. Nevertheless, Stokes found several useful exact solutions, and laid the foundations of one of the most important and challenging areas of applied mathematics.[631] From that date, the study of fluid dynamics blossomed, particularly in Britain and in the hands of Cambridge-trained mathematicians, as powerful new mathematical techniques and acute physical insights were brought to bear. But in many situations, especially the prediction of the resistance experienced by bodies moving through gases or liquids, agreement between theory and experiment was to remain elusive, and empirical methods remained necessary.[632]

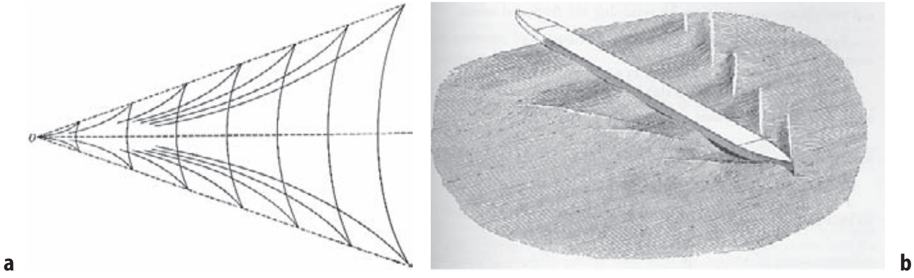


Figure 21. Thomson's asymptotic representation of ship waves. (**a**) The two families of waves restricted to a wedge-shaped region of half-angle 19° 28′. (**b**) An impression of the dominant disturbances, where the two wave systems coalesce (drawing by R.E. Froude, but the long ship is misleading, as Thomson modelled it by an intense pressure disturbance at a single moving point). [From Lamb (1895), pp.402, 403.]

[629] Darrigol (2003; 2005); Craik (2004; 2005).

[630] Darrigol (2002; 2005).

[631] See also Chapter 8, pp.191, 192.

[632] See e.g. Darrigol (2005).

The practical topic of ballistics was advanced by Francis Bashforth, who was acknowledged as the greatest British expert of his day. He devised the "Bashforth Chronograph", later described in an 1890 book of the same name. His *Mathematical Treatise on the Motion of Projectiles* (1873) became a standard work, and the series of experiments that he conducted led to great improvements of the Army's artillery, whose muskets and cannons had been exposed as antiquated and inefficient during the Crimean War. As recreation, he collaborated with his Cambridge contemporary, John Couch Adams, on a treatise on capillary action (Bashforth 1883). It was in this connection that the *Adams-Bashforth method* of successive approximation was invented, to compute the shapes of water droplets. Though Bashforth derived the equation, it was Adams who developed the method of solution: this still remains one of the standard numerical methods for solving differential equations.

Another who studied the effect of air resistance on rapidly moving projectiles was P.G. Tait; but Tait's motivation was not ballistics but golf, of which he was passionately fond. Tait's papers on the flight of spinning golf balls were perhaps the first-ever ventures into what is now called "sports science". Finding that their flight did not agree well with Bashforth's ballistic tables, he realised that this was attributable to the important role of "underspin", which imparted lift and so prolonged the flight of the ball. It is part of golfing lore that he predicted the maximum possible length of a golf drive, only to see it exceeded by his own son Freddie, a British amateur champion. But this is a travesty of the truth, the maximum length referred to being that *without* "underspin".[633]

Many works on dynamics were produced by Cambridge tutors for student use. Although most need not be mentioned, a few original works stand out. The able but sadly short-lived W.J. Steele (2nd, 1852) collaborated with Tait on *A Treatise on the Dynamics of a Particle* (Tait & Steele 1856), that was a marked improvement on earlier student texts in both style and content. Tait updated this work in several later editions, but always left the deceased Steele's portion intact. P.G. Tait's later collaboration with William Thomson on their influential two-volume *Treatise on Natural Philosophy* (1867) proceeded intermittently and at times frustratingly. Further volumes covering the rest

[633] Knott (1911), p.25. Tait's rather fierce expression in some portraits—for instance Figure 12 (e)—indicates just part of his true nature. Though Tait could be a forthright antagonist, a golfing friend, J.L. Low, recalled the elderly Tait as "a venerable gentleman who was the oldest boy and the youngest old man we ever knew", on account of his enthusiasm and sense of fun: Knott (1911), p.53.

of physics never materialised; but the authors succeeded in placing energy centre-stage in a brilliant reformulation of dynamics as part of the wider physics of heat, motion and thermodynamics. Later, they issued a popular abbreviation, *Elements of Natural Philosophy* (1873). Some works of E.J. Routh approached the level of research monographs, particularly his *Treatise on the Stability of a Given State of Motion* (1877) and his *Treatise on the Dynamics of a Particle* (1898). Related to the work of Thomson, Tait and Routh is the earlier Hamilton-Jacobi theory, developed by William Rowan Hamilton and then Carl Jacobi in the 1830s: this variational formulation remains useful for many physical systems.

In hydrodynamics, earlier poor, old-fashioned works were consigned to oblivion by authoritative articles by Thomson and Stokes in the *Cambridge and Dublin Mathematical Journal* (1847–49). Soon, more worthy texts by Matthew O'Brien and William H. Besant appeared; but these, too, were superseded in the 1880s by the authoritative treatises of Horace Lamb (2nd, 1872) and Alfred B. Basset (13th, 1877). In the generation of wranglers following Stokes and Thomson, much valuable research in hydrodynamics was published by Lamb, Rayleigh, O. Reynolds, A.R. Forsyth, A.G. Greenhill, M.J.M. Hill and others. In elasticity theory, a definitive textbook was written by Augustus E.H. Love (2nd, 1885), Oxford's Sedleian Professor of Natural Philosophy during 1899–1940.

Light and the "Aether"

The first direct measurement of the velocity of light was made in 1849 by Armand Fizeau in France, using an ingenious apparatus comprising a mirror and rapidly rotating toothed wheel. But much earlier, in 1676, Ole Roemer in Paris had deduced an approximate estimate of the velocity from observations of small annual variations in observed times of eclipses of the moons of Jupiter: these variations occur because light has a greater or lesser distance to travel, depending on the relative positions of the Earth and Jupiter.

Much was understood about the behaviour of light by the mid-nineteenth century, but little was known for certain about its true character. Though some connection had been made between light and radiant heat, the identification of light as just the visible part of a wide spectrum of electromagnetic waves was still not appreciated. This had to await the development of electromagnetic field theory by James Clerk Maxwell between 1865 and 1873, and the experimental discoveries of Heinrich Hertz in 1887. In the early- to mid-nineteenth century, there was still an ongoing, and at times bitter, debate over whether light consisted of corpuscles or waves. The wave theory, as advanced by Fresnel, was accepted by the Cambridge-educated establishment led by

John Herschel, G.B. Airy and later G.G. Stokes; but some others, most notably David Brewster, remained loyal to Newton's corpuscular theory.

The corpuscular theory, whereby tiny moving particles were supposed to be emitted by bright sources, had the attraction of explaining how light could travel at great speed through empty space. In contrast, it was hard to conceive how waves could propagate in this way, because experience suggested that waves had to be supported by some medium that permitted bodily deformations. Water waves and vibrating membranes involved displacements of a bounding surface. Sound waves travelled through air as longitudinal compressions and rarefactions; but, unlike light, they could not propagate through a vacuum.

Fresnel's experiments on refraction and polarisation strongly suggested that light waves (if they *were* waves) involved transverse, not longitudinal, displacements, that took place in planes perpendicular to the direction of wave propagation. The prevailing view was that light was transmitted by a perhaps weightless substance, called the "aether", that filled all of space, yet produced no noticeable resistance to the motion of solid bodies such as the planets. This aether was supposed to possess elastic, or jelly-like, properties, such that light was transmitted by its vibrations. (In the early seventeenth century, Descartes had proposed that such an aether actually moved the planets in their circular orbits around the Sun, by a sort of vortex motion. Though Newton's theory of gravitation brought an end to this vortex hypothesis, the idea of a light-supporting aether persisted.)

One consequence of the elastic aether assumption was that the mathematical theories of elasticity and fluid mechanics were for a long time closely connected with the theory of optics. For instance, Augustin Cauchy, George Green and George Stokes made valuable theoretical contributions to all three fields: it was a short intellectual step from waves in a fluid or elastic medium to optics in the "lumeniferous aether". Similarly, Archibald Smith published papers on the Fresnel wave surface in optics, and on wave propagation in an elastic medium.

But Stokes found it hard to accept the idea of an elastic aether that could nevertheless pass freely around, or perhaps even *through*, solid bodies like the planets. Accordingly, his 1850 theoretical study of the motion of viscous air close to an oscillating "ball pendulum" was undertaken, in part, as an analogue of the motion of the Earth through the surrounding aether.[634] Concerned to explain how the aether might flow around planets, Stokes proposed

[634] Surprisingly, he was then unaware that George Green had studied, a few years previously, the corresponding but somewhat easier non-viscous problem.

that it resembled "glue water" (much like wallpaper paste), that could undergo rapid elastic vibrations but also allow the passage of slow-moving solid bodies.

Stokes' mathematical analyses gave clear explanations of many optical phenomena that had previously been misunderstood or only partly understood. His topics included the rainbow, Newton's rings and related interference phenomena, diffraction, stellar aberration, and fluorescence. His own simple experiments, conducted at home with rudimentary equipment, served well to stimulate his theoretical imagination, but they were hardly state of the art. Later, he collaborated with the experimenter William Crookes on cathode rays and X-rays. Because Stokes and Crookes interpreted cathode rays as attributable to particles, rather than waves, they reignited the wave-versus-particle debate that had seemed decided in favour of waves.[635]

In 1835 and 1839, James MacCullagh of Dublin had proposed an alternative model of the aether, suggesting that the vibrations of light were associated with local *rotations* of particles of aetherial matter. Though MacCullagh's model produced equations that greatly resembled those of Maxwell's later electromagnetic theory, his hypothesis was considered too fanciful to find favour. But in 1867 William Thomson adapted MacCullagh's notion, combining it with ideas of Michael Faraday, Hermann Helmholtz and W.J.M. Rankine. The result was his ingenious *vortex-aether* hypothesis, which was a bold attempt at a "theory of everything".

In this, the aether was regarded as a fluid full of microscopic vortex motions. Because vortices can sustain oscillations, resist deformation, and even bounce off one another, they mimic elasticity: and so, in theory, they could transmit light just like the supposed elastic or "glue-water" aether. But Thomson (and Rankine before him) went further in suggesting that *matter itself* was composed of such vortices organised in a certain manner. Each "atom" of a particular substance was envisaged as a closed vortex with a particular "knotted" form: there would be as many different kinds of substances as there were kinds of knots (see Figure 22). Furthermore, the recently observed spectral lines of incandescent matter—such as the distinctive double line of sodium—might correspond to the characteristic vibrations of the particular vortex atoms of the material. Thomson even hoped to incorporate electrical and magnetic effects into this theory.[636]

[635] Only with the development of quantum theory in the 1920s by Erwin Schrödinger, Werner Heisenberg, Nils Bohr and Paul Dirac was the strange wave/particle duality of electromagnetic radiation finally incorporated into a consistent mathematical theory.

[636] Whittaker (1951); Smith & Wise (1989).

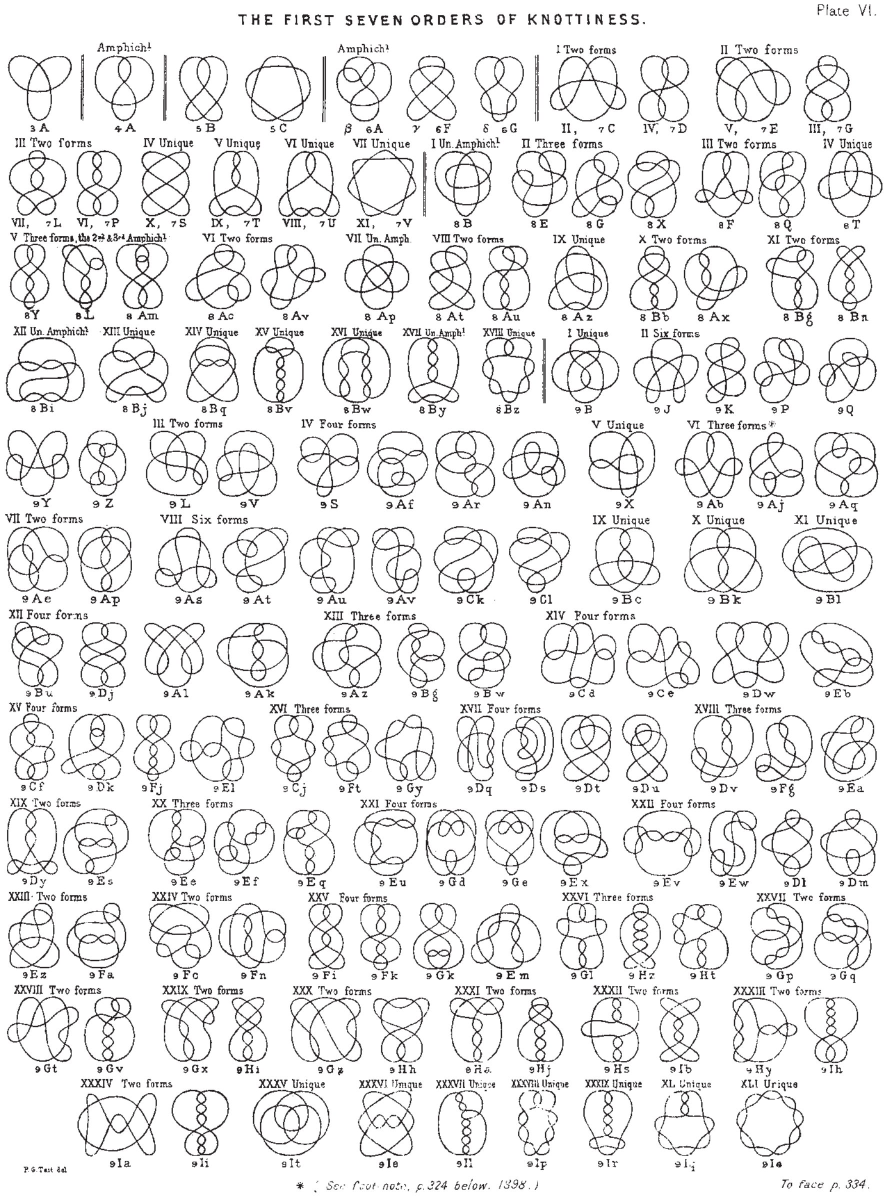


Figure 22. Tait's classification of "the first seven orders of knottiness". [From Tait (1898), facing p.334.]

James Clerk Maxwell was also interested in the vortex-aether theories, and had proposed his own variant. This had arrays of hexagonal vortex cells separated by thin layers containing "idle-wheel" particles. The rotation within the vortices was supposed to represent the magnetic field, and the movement of "idle-wheel" particles modelled the flow of electric current.[637]

Thomson's speculations led to a considerable body of work on the supposed vortex atoms, and on vortex motions generally. Thomson's "vortex atom" paper was devoid of mathematics, but he followed it with several important mathematical papers on vortex motion in fluids, clearly motivated by his grand idea. Though much interested in Thomson's work on vortices, G.G. Stokes remained sceptical of the vortex-atom conjecture, rightly believing that such arrays of vortices must be highly unstable. But J.J. Thomson (2nd, 1880; appointed Cavendish Professor of Experimental Physics in 1884) was sufficiently intrigued to write a treatise on *The Theory of Vortex Rings* (1883), before his own discovery of the electron dealt a final death-blow to the vortex-atom conjecture.[638]

William Thomson's intermittent collaboration with P.G. Tait of Edinburgh University led the latter to conduct dramatic experiments with smoke rings, and he also began a systematic theoretical classification of knots. Tait extended his classification in collaboration with an elderly vicar, Thomas Penyngton Kirkman, to describe all knots with 8, 9, and 10 crossings. This work duly took its rightful place as part of the mathematical theory of topology. Kirkman had studied at Trinity College, Dublin, and was the author of many mathematical papers on combinatorics, graph theory and group theory. Remarkably, all his work on knots was performed after the age of seventy-seven—an encouragement to all ageing mathematicians. Though Thomson's vortex-atom theory ended in failure, it had led to considerable advances in fluid dynamics and in knot theory.

Finally, J.C. Maxwell's early work on colour vision should be mentioned. His aim was to construct a quantitative theory of colour perception. Extending previous studies by D. Brewster, J.D. Forbes and D.R. Hay in Edinburgh, Maxwell's largely experimental studies were conducted between 1855 and 1860. Many of these involved simple but ingenious spinning tops, to which various segments of coloured paper were fixed. But he also experimented with rays of light, observing that superimposed blue and yellow rays did *not* produce green, although mixing blue and yellow pigments did so, as artists

[637] See Harman (1998), pp.102–105.

[638] But there has been a modern revival of knot theory in fundamental physics, in the theory of "superstrings".

had long known. And he found that an appropriate mix of just three pure rays of different colours could produce light perceived to be white. Though this was not the same as white light produced by the Sun, which contained a continuous spectrum of colours, it seemed so to the human eye. This supported the theory of Thomas Young, that the retina of the eye has just three distinct types of colour receptor: though all responded to a range of colours, each reacted most strongly to red, green and violet, respectively. Maxwell confirmed that colour blindness is usually the result of absent red receptors.[639]

Heat

As well as establishing the fundamental principles of a new field of mathematical study, Joseph Fourier's *Théorie Analytique de la Chaleur* of 1822 had developed a powerful new mathematical technique which transcended that field: that now known as *Fourier series*, which has widespread applications. But Fourier's theory was slow to penetrate to Cambridge: Philip Kelland's *Theory of Heat* (1837), written while he was still a fellow of Queens' College, revealed his imperfect understanding of Fourier's treatise, and it contained other flawed hypotheses.

At the age of just sixteen, William Thomson had already mastered Fourier's theory, and his first paper, submitted to the *Cambridge Mathematical Journal*, rightly criticised Kelland's book. Thomson's lifelong interest in heat and electricity began not in Cambridge but during his earlier studies at Glasgow. Both heat and electricity featured in the courses he took there in chemistry and in natural philosophy; and it was Glasgow's Professor of Astronomy, J.P. Nichol, who first introduced him to Fourier's work. But his interest in the heat of the Sun and the Earth, and the geological and cosmological implications, probably derives from William Hopkins.

One of Thomson's interests was the gradual cooling of the Earth, and whether its characteristics could be used to estimate the age of the Earth and the thickness of its solid crust. William Hopkins had also addressed such topics between 1836 and 1857. Hopkins had suggested that the Earth, though originally molten, might now have cooled to the extent that it was virtually solid throughout, apart from isolated cavities of molten and gaseous matter: these cavities provided the "elevatory force" which he believed to be the source of most geological activity. But the temperature of the Earth was known to rise with depth below the surface in deep mines: this had been

639 See Harman (1998), pp.37–48.

measured as about one degree Fahrenheit for every fifty feet of depth. Accordingly, the temperatures of the interior could be such that rock remained in a molten state, contrary to Hopkins' initial hypothesis.

During 1851–57, Hopkins collaborated with James Joule and the engineer William Fairbairn of Manchester to investigate changes in the melting points and conductivities of substances under large pressures: Thomson was also collaborating with Joule at this time, and took a keen interest in the Joule-Fairbairn-Hopkins work. Though they mainly investigated substances such as wax that melt at low temperatures, their results showed that the melting point does increase with pressure, at least in some cases. By implication, this supported Hopkins' view that very hot rock under sufficient pressure may be solid rather than liquid. In a related study, J.D. Forbes had measured the thermal conductivity of volcanic "trap rock", finding that this increased with depth and so with pressure.

The idea that the Earth was gradually losing its original "primitive" heat accorded with the many observations of fossil tropical vegetation in now temperate climes; but it seemed inconsistent with the existence of a previous, and not-too-distant, ice age when glaciers covered large areas now in fruitful cultivation. But Hopkins argued that such climatic changes were superficial phenomena largely independent of the Earth's internal heat, influenced more by changes in the distribution of land and sea, and particularly by ocean currents such as the Gulf Stream of the Atlantic.

In 1854–56, both Thomson and Helmholtz addressed the question of the cooling of the Earth: Helmholtz estimated that it would have taken 350 million years for the Earth's core to cool from 2000 to 200 degrees Centigrade; and, at the present time, the heating of the Earth's surface from below accounted for an increase of only one-thirtieth of a degree above that due to heating by the Sun. Thomson's calculations, based largely on Fourier's theory of heat conduction within *solids*, led to upper and lower estimates of 400 million and 20 million years for the time since the Earth was a uniformly hot molten body. And he thought that plants could have existed on the surface only for a few million years.

Thomson's work of 1862–63 on the rigidity of the Earth supported the view that the Earth's cooling had formed it into a mainly solid structure. Hopkins had earlier argued that the observed precession and nutation of the Earth indicated that it was almost entirely rigid, because a mainly liquid Earth within a relatively thin rigid outer shell would behave very differently. Though, to his embarrassment, Thomson now believed Hopkins' calculations to be "all wrong", he accepted that the general conclusions were probably valid. Thomson's new work suggested that even a solid Earth would exhibit tides, as it responded elastically to the periodic pull of Sun and Moon. As these tides would be in phase with those of the oceans, the observed oceanic tides at the Earth's surface should be much reduced, compared with those seen from the surface of a truly rigid Earth. To account for the tides actually observed, Thomson concluded that the Earth must be "more rigid for instance than steel", and the thickness of its solid crust likely to be more than two thousand miles.[640]

Related mechanical calculations concerned the gradual slowing of the Earth's speed of rotation, caused by the action of the tides and the resulting tidal friction. In 1866, Thomson estimated that the Earth's daily period increased by about 3.6 seconds per year, making it "a very untrustworthy timekeeper." This estimate was later reduced to 2.2 seconds per year, in improved calculations worked out by J.C. Adams along with Thomson and P.G. Tait.

Others of Thomson's calculations estimated the time it would take for all the energy of the Sun to be consumed, caused by its gradual depletion by radiation of heat and light. Convinced that the Sun was not simply losing the residual "primitive heat" created at its formation, he examined various mechanisms for heat generation. He dismissed frictional heating by internal motions, and chemical heating by burning of its matter in an oxygen-rich atmosphere. These were insufficient to maintain the Sun in the nearly steady state that had persisted for the past six thousand years. He considered replenishment of the Sun's mass by a regular supply of falling meteorites: these not only provided chemical fuel but, more importantly, converted their large kinetic energy into heat on impact. For a time in the early 1850s, he believed that his "meteoric matter theory" was the answer: confidently answering sceptical objections by Stokes, he estimated that the Sun had illumined the Earth only for a remarkably short time of about 32,000 years.

In 1854, Hermann Helmholtz realised that a cooling Sun would contract in size, and thereby convert some of its own gravitational potential energy into new heat. Accordingly, cooling would take place more slowly than predicted by radiation alone. By 1861, Thomson was convinced that this effect was greater than that of his meteorites, and he adopted Helmholtz' model to revise his estimate of the age of the Sun to between twenty and a hundred million years. But this estimate was still far too small for the geologists to accept. Thomson was not to know that his estimates were invalidated by the energy released by thermonuclear reactions within the Sun: the actual age of the Earth is now estimated as 4500 million years. Even after Ernest Rutherford's discovery, in the early years of the twentieth century, of the energy released

---

640 In this, he was broadly correct: the rigidity of the Earth's crust is indeed comparable with that of steel, and its thickness is very roughly half that of the Earth's radius.

by radioactive decay, the elderly Thomson (by then Lord Kelvin) remained unconvinced of its role.

By his work on the age of the Earth and the lifetime of the Sun, Thomson was inevitably drawn into the controversies raging among scientists and theologians. He met much opposition from geologists, especially Sir Charles Lyell, who supported the Uniformitarian, non-progressive, theory of the Earth: but this was unsustainable if the energy of the solar system was continually being depleted, as both Hopkins and Thomson rightly claimed. Thomson's estimate of the age of the Earth, at around 100 million years and perhaps as little as 20 million years, was also too short for the Progressionists: it contradicted a growing weight of geological evidence that supported a far greater age. And it was similarly far too short a time for Darwin's proposed biological evolution to have taken place.

Though "progressive" in geological matters, the positions of Hopkins, Stokes and Thomson on evolution in biology remained equivocal. Thomson's own scientific estimates disagreed with the geologists' datings; and he firmly believed that there had been insufficient time for evolution of species by natural selection. Though he did not rule out an evolutionary contribution, he held the common view that divine intervention must also be implicated. He also proposed that early life forms might have been brought to the Earth by meteorites: an idea ridiculed by T.H. Huxley, as "'creation by cockshy'—God Almighty sitting like an idle boy at the seaside and shying aerolites (with germs), mostly missing, but sometimes hitting a planet!"[641]

Thomson's differing estimates of the age of the Earth and Sun were taken more seriously than they deserved, because of his high standing as a natural philosopher. He was forced to make many speculative hypotheses in order to reach even order-of-magnitude estimates, and many have not withstood later scientific advances. Even in his own day, the validity of his assumptions encountered some forthright opposition. His antagonist T.H. Huxley did not dispute Thomson's mathematical skills, but rightly warned that: "mathematics may be compared to a mill of exquisite workmanship, which grinds you stuff of any degree of fineness; but nevertheless, what you get out depends upon what you put in; and as the grandest mill in the world will not extract wheat-flour from peascods, so pages of formulae will not get a definite result out of loose data."[642]

Thomson's study of heat was intimately connected with his ideas on energy conservation and dissipation, and these led to fundamental advances far

[641] Huxley (1918), v.2, pp.165, 166; also quoted by Smith & Wise (1989), p.642.

[642] Huxley (1908), p.335; also quoted by Smith & Wise (1989), p.586.

more important than his work on the age of the Earth. The experiments of James Prescott Joule convinced him that *total energy was conserved* when mechanical energy was lost to heat generated by friction, and also when heat was converted into mechanical energy. Though energy tended to dissipate into less useful forms, it never disappeared. The temperature, density, and pressure of gases were connected by known laws. These were part of the new theory of *thermodynamics*, pioneered in France in the 1820s by Sadi Carnot's studies of steam engines, and taken up by Joule, Thomson, Rankine and a few others in Britain in the 1840s and 1850s. Carnot had proposed that heat was conserved as a substance known as "caloric", but this had been disproved by Joule. Versions of the first and second laws of thermodynamics were enunciated by Thomson in a paper of 1851, in which he gave due credit to the work of Joule, Carnot and Clausius. It was for this work that the absolute temperature scale, in degrees Kelvin, was later named in Thomson's (i.e. Lord Kelvin's) honour. The new subject of thermodynamics developed alongside revolutionary technological improvements in steam engines and other machinery. Energy was the major theme of Thomson's and Tait's two-volume *Treatise on Natural Philosophy* (1867); and Tait's popular textbook on *Thermodynamics* (1868) was the first so named.

It was recognised that the temperature of gases was related to the degree of agitation of its particles (in fact molecules), and that pressure was the average force per unit area exerted by the gas particles on colliding with a surface. In the 1860s, this idea was taken to new heights by Rudolf Clausius, James Clerk Maxwell, and later by Ludwig Boltzmann: their kinetic theories of gases showed how statistical distributions of randomly moving particles give rise, as averages, to the observable properties of density, temperature and pressure; and, even more impressively, explain both heat conduction and viscosity in terms of collisions of particles. An even earlier meritorious attempt at a kinetic theory of gases, by the Edinburgh-educated John James Waterston, had been denied publication by the Royal Society in 1845. Waterston had spent time in India and had few scientific contacts in Britain. Sadly, a novel and speculative theory by an unknown outsider, that did not fit into the current stream of establishment research, was always likely to meet with scepticism and lack of understanding. The rediscovery of Waterston's manuscript by Lord Rayleigh, and its belated publication in 1892 in the *Philosophical Transactions of the Royal Society*, gave posthumous recognition of his achievement.[643]

643 Smith & Wise (1989), Ch.14–18; Truesdell (1979); Olson (1975), Ch.9.

Maxwell's kinetic theory of gases starts with the assumption that the molecules of a gas behave as tiny particles like perfectly elastic spheres. They have velocities that are randomly distributed, and they are free to collide with and bounce off each other. Maxwell showed that the gas is in a state of equilibrium, in an averaged sense, when the particle velocities are distributed according to the normal law, now also known as the "Maxwellian distribution" (See Figure 20). The averaged kinetic energy of the particles, per unit volume of space occupied by the gas, is a measure of its temperature. Thermal diffusion takes place when a hotter gas is placed next to a colder one: this is because, on average, hotter particles enter the space occupied by the colder gas, and colder particles enter the space of the hotter gas.

Rather similarly, diffusion of mean (i.e. average) momentum takes place when layers of gas are in (mean) relative motion, and this transfer of momentum determines the viscosity of the gas. Maxwell's "elastic sphere" model of the particles gave a value of viscosity that increased with the square root of the temperature of the gas. But his experiment of 1865 contradicted this finding, showing instead that the viscosity increased linearly with temperature. Accordingly, he developed another model of the particles, postulating small bodies that exerted a repulsive force on each other, with magnitude that was some inverse power of the distances between them. On carrying through his analysis, he found that an inverse fifth power of the distance gave the required behaviour. Maxwell's theory was later usefully expounded in H.W. Watson's *A Treatise on the Kinetic Theory of Gases* (Watson 1876).

The statistical nature of Maxwell's gas means that his theory's conclusions are only true on average, and not in every conceivable case. He used this fact to indicate the correct interpretation of the *second law of thermodynamics* as a statistical, and not a mechanical, law. To do so, he envisaged a "thought experiment". A hot and a cold gas are separated by a diaphragm containing a small hole that allows individual particles to pass from one side to the other. The hole may be opened or closed at will by a "finite being" able to see and measure the velocity of approaching particles. If a particle approaching from the "hot" side has speed greater than the average speed of particles of the cold gas, it is not allowed to pass; but if its speed is less that the average for the cold gas, it is allowed through. Conversely, a sufficiently fast-moving particle is allowed to pass from the cold to the hot region, but slower-moving particles are not. After some time, the temperature of the hotter gas must increase and that of the cooler gas decrease. This is in apparent contradiction with the second law of thermodynamics, which requires heat to flow from the warmer to the colder body of gas. But, in statistical terms, there is a vanishingly small chance that such a contradiction will ever happen.[644]

Electricity and Magnetism

The construction of iron-reinforced ships gave practical impetus to the study of magnetism, for traditional magnetic compass needles were rendered unreliable by the magnetic attraction of the iron. To compensate for the attraction of the hull, correcting pieces of metal had to be situated around the ship's compass. Archibald Smith, a keen amateur sailor, was one who made a major study of this important problem. With initial encouragement from Sir Edward Sabine, Smith worked intermittently on the topic between 1842 and 1862, while also pursuing a legal career. He published practical tables, formulae and graphical methods, and in 1862 helped compile *An Admiralty Manual for Applying the Deviations of the Compass Caused by Iron in a Ship*. Smith had used methods developed by Poisson and by Fourier, improving on earlier work by Airy which made approximations that were potentially dangerous to shipping. William Thomson corresponded with Smith about this work; and, after Smith's untimely death in 1872, himself designed an effective ship's compass, manufactured in a Glasgow factory that he jointly owned. From 1883, this compass began to be fitted in ships of the Royal Navy, and by 1890 it totally displaced the Admiralty's own. For another ten years, it remained the state-of-the-art choice for both warships and commercial vessels.[645]

Following on from the work of Lagrange, Laplace and Poisson on "potential theory" applied to electro- and magneto-statics, important mathematical advances had been made, in unlikely circumstances, by George Green. Green's long-neglected *Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism* (1828) was eventually hailed as a milestone in the theoretical development of these subjects. This essay, and Green's later studies at Cambridge, were considered in the first section of Chapter 8.

The interaction between electric currents, magnetic fields, and moving electric conductors began to be uncovered by the pioneering experiments of Michael Faraday at the Royal Institution in London. (From these derive the principles of the electric motor.) In 1831, he discovered electromagnetic induction; and his account of his experiments provided a major impetus for

---

[644] See e.g. Harman (1998), pp.138, 139, 176–178. Maxwell's "finite being" was dubbed "Maxwell's demon" by William Thomson, but Maxwell disliked the expression.

[645] Smith & Wise (1979), Ch.22.

William Thomson's and James Clerk Maxwell's later fundamental theoretical advances.

Before Maxwell's time, an attempt had been made by William Whewell and others to incorporate electricity and magnetism into the Cambridge Tripos syllabus. But this proved unsuccessful, because the questions were routinely ignored, and the subjects were deleted in 1849 by the newly formed Board of Studies, just before Maxwell became a student. Related to this attempt, Whewell prepared a "Report on the Recent Progress and Present Condition of the Mathematical Theories of Electricity, Magnetism, and Heat" for the 1835 meeting of the British Association. Also, with Whewell's encouragement, Robert Murphy (3rd, 1829) of Caius College had written his *Elementary Principles of the Theories of Electricity, Heat and Molecular Actions* (1833) intended for student use. Much later, William Thomson commended Murphy's work for its satisfactory treatment, but its direct influence was small. Murphy also wrote twenty-two research papers on electricity and other mathematical topics.

Faraday used no mathematics in his descriptions, being opposed to all symbolic representations because of his adherence to a religious sect called the Sandemanians. But, in the hands of Thomson and Maxwell, Faraday's clear verbal accounts were eventually transformed into a coherent, if sometimes ill-organised, group of mathematical theories. Thomson's papers of the 1840s sought to unify electricity and magnetism into a single theory; and, in the 1860s, Maxwell built on these to develop his own ideas, culminating in the 1873 publication of his *Treatise on Electricity and Magnetism*. Maxwell's work displaced the rival continental theories of Oersted, Ampère and Wilhelm Weber, but Thomson himself was never totally convinced.[646]

Throughout his career, Maxwell used geometrical and physical analogies to sharpen his insight. For instance, his early study of Faraday's "lines of force" in electricity and magnetism exploited similarities with fluid flow, where streamlines took the place of magnetic or electrical lines of force. His analogues and theoretical models of electromagnetic phenomena were not necessarily compatible with each other, though each served an immediate purpose. For this reason, and also his mixing of experimental and theoretical chapters, Maxwell's *Treatise* is difficult and sometimes confusing for the reader. Though he included clear statements of what are now known as *Maxwell's equations of electromagnetic field theory*, Maxwell did not himself seem

[646] Wilson (1987); Smith & Wise (1989). Other mainly experimental work of William Thomson on electricity, stemming from his involvement with the first successful transatlantic telegraph cable, is described below.

to regard these equations as the cornerstone of the subject that they are now recognised to be. Only later, after the experiments of Hertz on electromagnetic waves, and the initially controversial theoretical reworking by the English outsider Oliver Heaviside, was the theory of electromagnetism definitively established.

Maxwell believed in an all-pervading aether; but from the 1880s the electric and magnetic fields themselves were placed at the heart of the theory. Maxwell's equations now represented the coupled behaviour of electric and magnetic fields, charges and currents, at last divorced from any supposed aether that had previously been thought necessary to support them. Reworkings of Maxwell's theory by Heaviside and the American Josiah Willard Gibbs gave it its modern form; while, at Cambridge, a new generation led by J.H. Poynting, J. Larmor and J.J. Thomson vigorously advanced the Maxwellian tradition.[647]

The interplay of theory and experiment was a dominant feature of the researches of both Thomson and Maxwell. One of Maxwell's preoccupations, both before and after moving to Cambridge, was the establishment of standardised units of electricity and magnetism. For the British Association for the Advancement of Science, he and his co-workers determined the standard unit of resistance, the "ohm", that was subsequently used by all electricians and physicists.

Maxwell's determination of the units of electrostatics (based on the force between charges) and magnetism (based on the force between magnetic poles) led to a fundamental discovery. By his electromagnetic theory, he knew that the ratio of these units had the dimensions of a velocity, and that this quantity was the velocity of propagation of plane electromagnetic waves. But it was only when he discovered that this ratio was nearly the same as the known velocity of light that he realised that light waves themselves were almost certainly electromagnetic. This was later confirmed by Heinrich Hertz.[648]

Mention must also be made of the remarkable physical laboratory that was built in the early 1870s at the new Imperial College of Engineering in Tokyo. This was planned by its Principal, Henry Dyer, and by William E. Ayrton, the professor of Natural Philosophy and Telegraphy. When they were joined in 1875 by John Perry, the professor of Civil Engineering, he "found a marvellous laboratory, such as the world had not seen before." Dyer had studied at Anderson's College in Glasgow, Ayrton at University College, London and

[647] Whittaker (1951); Hunt (1991); Harman (1998); Darrigol (2000); Warwick (2003).

[648] See e.g. Hunt (1991), Harman (1998), Warwick (2003).

Perry at Queen's College, Belfast; and both Ayrton and Perry had for a time assisted William Thomson in Glasgow. In Tokyo, they pursued researches on magnetism, electricity and telegraphy (all subjects dear to Thomson), to the extent that Clerk Maxwell commented that they threatened "to displace the centre of electrical development . . . quite out of Europe and America to a point much nearer to Japan." Ayrton and Perry later resumed their collaboration at Finsbury Technical College in London, and had considerable influence on the development of technical education in Britain as well as Japan. William Thomson also fostered Japanese physics more directly, through the several young Japanese who visited his Glasgow laboratory to work with him.[649]

Pure Mathematics and Mathematical Methods

The English translation, by Babbage, Herschel and Peacock, of Lacroix's elementary treatise on the calculus was published in Cambridge in 1816 (Lacroix 1816). A year earlier, William Wallace had given the first complete account in English of the differential calculus in "continental" notation: a long article in the *Edinburgh Encyclopaedia*, inappropriately entitled "Fluxions". In this, Wallace explicitly employed the "doctrine of ratios" of vanishingly small quantities. Soon, more texts and books of worked examples appeared.

Henry Parr Hamilton and John Hymers published Cambridge textbooks on analytic geometry in 1826 and 1830 respectively; and George Peacock's lengthy and influential *A Treatise of Algebra* also appeared in the latter year. Though not a calculus textbook, Peacock's work discussed the algebraic foundations of differential calculus in the manner of J.L. Lagrange, seemingly avoiding ratios of vanishingly small quantities. In 1831, James Thomson's *Introduction to the Differential and Integral Calculus* was published in Belfast, where Thomson was then teaching; and a much-revised second edition was issued in London in 1848. At Cambridge, John Hymers' *A Treatise on the Integral Calculus* was also published in 1831, later joined by his *A Treatise on Dif-*

649 Among Thomson's Japanese researchers were the influential Tanakadate Aikitsu and Shida Rinzaburo. P.G. Tait also had Japanese contacts, and encouraged his Edinburgh students C.G. Knott, D. Marshall and J.A. Ewing to take up appointments at Tokyo Imperial University. The founding of the College of Engineering in Tokyo, with Glasgow-educated Henry Dyer as its first head, owed much to advice of W.J.M. Rankine. But the first Japanese students to study in Britain attended University College, London, and a few later attended Cambridge, most notably Kikuchi Dairoku (19th, 1877), who became Professor of Mathematics and later President of Tokyo Imperial University. See Checkland (1989); Craik (2007).

ferential Equations, and on the Calculus of Finite Differences in 1839; and William Hallowes Miller's *An Elementary Treatise on the Differential Calculus* appeared in 1833. Thomas Grainger Hall of King's College, London published in 1834 *An Elementary Treatise on the Differential and Integral Calculus*, again with a Lagrangian slant. This became the standard textbook at King's College and was republished in several later editions.

From 1835, some worthy and inexpensive mathematical texts were published by the Society for the Diffusion of Useful Knowledge. Among the first were those by Samuel Waud, William Hopkins and Augustus De Morgan, respectively on algebraic geometry, trigonometry, and differential and integral calculus. Robert Murphy, as well as working on electricity, wrote *A Treatise on the Theory of Algebraic Equations* (1839). The debt-ridden Murphy had obtained this commission on the recommendation of De Morgan. But Murphy died not long after, and De Morgan noted in his copy of the book that "He kept body and soul together while writing it, and, I think, did the same for the subject."[650]

Duncan F. Gregory's *Examples of the Processes of the Differential and Integral Calculus* (1841) was intended as a successor to an earlier compilation by Peacock (1820). And Peacock himself prepared an extensive *Report on the Recent Progress and Present State of Certain Branches of Analysis* (1834) for the British Association for the Advancement of Science. These works collected together a wealth of results and challenging examples, culled mainly from continental sources, and they did much to raise the standards of mathematical analysis in Cambridge. From 1852, the most popular calculus textbook was Isaac Todhunter's *Treatise on the Differential Calculus, and the Elements of the Integral Calculus*. This was later expanded as separate texts on differential and integral calculus, and published in many editions, well into the twentieth century.

D.F. Gregory's own original papers were published mainly in the early volumes of the *Cambridge Mathematical Journal* which he founded and edited.[651] Though some of the articles are rather slight, being elegant solutions of problems of the kind set in the Tripos, others show Gregory's proficiency in the symbolic calculus of operators, for solving both differential equations and difference equations.[652] Gregory also sought to give geometrical

[650] Crilly (2004b).

[651] These were republished some time after his death in a volume edited by William Walton, along with a biographical memoir by Robert Leslie Ellis (Gregory 1865).

[652] This subject was originated by L. Arbogast of Strasbourg around 1800, but was then little studied: among other enthusiasts in Britain were Augustus De Morgan, Robert Leslie Ellis, George Boole, William F. Donkin and Alexander J. Ellis.

interpretations of imaginary and complex quantities, envisaging algebraic curves as having both real and imaginary branches. The origins of such work can be traced to John Playfair and George Peacock, and later extensions were conducted by Gregory's friend William Walton.

Some time after the deaths of both D.F. Gregory and R.L. Ellis, William Walton edited their writings (Walton 1863; 1865). Earlier, Walton had completed a work begun by Gregory, *A Treatise on the Application of Analysis to Solid Geometry* (Gregory & Walton 1845) to which William Thomson, Hugh Blackburn and W.F.L. Fischer also contributed. Many of Ellis' "other writings" were previously unpublished, but his mathematics had mostly appeared, like Gregory's, in the *Cambridge Mathematical Journal.* Again, some pieces are slight; but others are knowledgeable contributions to the theory of probability, the method of least squares, the evaluation of definite integrals, and functional equations. Ellis' most substantial piece is his 85-page "Report on the Recent Progress of Analysis (Theory of the Comparison of Transcendentals)" commissioned for the sixteenth meeting of the British Association for the Advancement of Science in 1846. This is both a comprehensive historical survey and an up-to-date review of the literature, mainly from continental journals then little-known in Britain. The theory of elliptic functions, together with its extension and related work by Legendre, Hermite, Jacobi, Abel, Liouville and many others, are expertly summarised. Although it contained no new results, Ellis' convenient account must have been of great value to the British mathematical community, still struggling to catch up with continental scholars.

Valuable in a different way were the editions of Euclid's *Elements* published by Robert Potts (26th, 1832), who worked in Cambridge as a private tutor. His scholarly edition of Books 1–6, 11 and 12 appeared in 1845 and a substantial Appendix in 1847. A shortened edition for schools was first published in 1846 and was reprinted in several later editions: these were much used in schools throughout the English-speaking world.

Some of the work already described on the various physical applications of mathematics entailed the creation of new mathematical concepts and techniques. Many were readily transferable to other fields of application, and several were later extended and generalised into wider contexts and more abstract forms. In this way, new areas of pure mathematics were opened up. The work on knots by Tait and Kirkman is a remarkable example: a flawed physical conjecture stimulated an area of study now regarded as pure mathematics remote from practical applications. But most of the advances that arose from applications concern developments in *mathematical analysis.*

The theory of Fourier, developed in his study of heat, gave rise to one of the standard techniques of the analysis of functions. On any finite interval, this allows the representation of an arbitrary mathematical function as an infinite sum of wavelike (sine and cosine) components. Such Fourier series, and their later generalisation as Fourier integrals on infinite domains, are still much used in the solution of ordinary and partial differential equations. Related work of Stokes and Thomson on waves and series led to several important mathematical discoveries. Stokes discovered some of the first-known examples of the *non-uniform convergence* of series; and, in connection with studies of the rainbow, he arrived at import insights into the nature of asymptotic approximations of integrals. In the latter connection, his name is commemorated in the *Stokes phenomenon*.[653]

Thomson's main contribution to asymptotics was his *theory of stationary phase*. Developed to describe the form of localised "packets" of surface water waves, this exploited the fact that superpositions of waves of differing lengths, as in Fourier integrals, mostly cancel one another out; but that, under certain conditions, the waves instead locally reinforce one another. Thomson's simple mathematical approximation, dominated by this local reinforcement, gives remarkably good results in situations previously regarded as very complicated or intractable (see, e.g. Figure 21).

A general analytical result, now known as *Stokes' theorem*, connects surface integrals and line integrals taken around the periphery of the surface. This result was actually discovered by William Thomson, and described to Stokes in one of the many letters that they exchanged.[654] This theorem is a generalisation of an earlier one attributed to George Green, known as *Green's theorem in the plane*. And the latter is itself a two-dimensional reduction of the far more general *Green's theorem* first given in Green's *Essay* of 1828. Green's powerful theorem gave a means of re-expressing integrals over an arbitrary three-dimensional volume in terms of (hopefully simpler) two-dimensional integrals taken over the surface containing the volume. By its application, and by elaborating the concept of the "potential" in the contexts of electricity and magnetism as well as in gravitation, Green became one of the main founders of potential theory. Green's technique of solving differential equations by means of what are now called *Green's functions* has also become a standard part of mathematical analysis, much used in fields such as quantum theory that Green never dreamed of.[655]

[653] More details were given in Chapter 8.

[654] Stokes first published the theorem in the Smith's Prize examination paper of 1854, when Maxwell was a candidate.

[655] See also Chapter 8 and Appendix A.

In addition to his many other concerns, William Thomson was interested in automatic calculating devices (as was his brother James). As well as his tide recorder and predictor, he published papers on "continuous calculating machines" for solving simultaneous linear algebraic equations, for performing integrations, and for solving differential equations. These were all mechanical analogue devices, involving strings, levers and pulleys, or rolling discs, cylinders and globes.[656] Accordingly, their principles were a far cry from Babbage's uncompleted differential and analytical engines, which were closer in concept to modern digital computers. For the latter, the *Adams-Bashforth algorithm*, developed by John Couch Adams, is still used as an efficient means of performing lengthy calculations.

Though Stokes, Thomson and Maxwell dominated the scientific world of their day, the greatest pure mathematicians among our wranglers were undoubtedly Arthur Cayley and James Joseph Sylvester. These two became friends when working in London, Cayley as a lawyer and conveyancer and Sylvester as an actuary with the Equity and Law Life Assurance Society, while both pursued mathematical research in their spare time. Both published copiously on a wide variety of mathematical topics.

Though Cayley failed to inspire a vigorous research school of pure mathematics in Cambridge, his own output of more than nine hundred research papers was astonishingly prolific. A number of his papers concerned applications, but the large majority were contributions to pure mathematics. Cayley made substantial advances in most areas of modern mathematics, especially matrix algebra and other algebraic structures, the theory of permutations, analytic geometry, non-Euclidean and n-dimensional geometries, group theory, graph theory and especially the theory of algebraic invariants.

It is inappropriate to attempt to describe these pure mathematical topics here, because this would require too much technical exposition. But sometimes a mathematical question can be disarmingly simple, yet disconcertingly difficult to answer. In 1878, Cayley asked just such a question at a meeting of the London Mathematical Society: "Has a solution been given of the statement that in colouring a map of a country, divided into counties, only four distinct colours are required, so that no two adjacent counties should be painted in the same colour?" This is the famous "four-colour problem", well known as a practical rule among map makers, but not proved in generality until recent times.

For much of his life, Cayley was Britain's leading pure mathematician, and he stoutly supported the study of mathematics for its own sake, as a thing of

---

[656] See Thomson & Tait (1879), v.1, Appendix B.

intellectual beauty. Nevertheless, he retained an interest in applications. He was consulted on mathematical points by leading applied mathematicians and physicists; he pioneered the use of mathematics in organic chemistry; he served for many years on the Council of the Royal Astronomical Society and was its President during 1872–74.

Early in his career, Cayley had been stimulated by his contacts with the Irish-based George Boole, William Rowan Hamilton and George Salmon, rather than by Cambridge mathematicians. The important *Cayley-Hamilton Theorem* of matrix theory was discovered by the two independently. As the creators of invariant theory and its various ramifications, Cayley, Sylvester and Salmon were to become known as the "invariant Trinity". A notable later contributor to invariant theory was Percy MacMahon, a Royal Artillery Captain who retired from active service to teach at the Royal Military Academy, Woolwich.[657]

James Joseph Sylvester's career, like his personality, was more turbulent than Cayley's. It is certain that he faced much prejudice because of his Jewishness: he was unable to graduate at Cambridge despite being second wrangler, he could not become a college fellow, and he failed to gain several appointments for which he applied. His various university and college appointments were outlined in the first section of Chapter 9.

Sylvester's teaching was always eccentric, firmly focussed on his current research, and paying little regard to the needs and limitations of students. A description of his personality as "fiery and passionate"[658] was perhaps an understatement. His publications, too, were individualistic, with a multitude of appendices, footnotes, and coinages of new words that made them hard to comprehend. He was proud of a work he had written on *The Laws of Poetry*, though this failed to command respect in literary circles. But his mathematical contributions were substantial and original, especially in the fields of matrix theory, invariant theory, and the theory of algebraic equations.[659]

---

[657] Cayley's pioneering work on matrix theory, though undertaken as pure mathematics, later found application in quantum mechanics and many other fields. Cayley's work is discussed authoritatively by Crilly (1986; 1988; 1999; 2004c; 2006). On MacMahon, see Turnbull & Crilly (2004).

[658] Macfarlane (1916), p.109.

[659] Definitive studies of J.J. Sylvester, his published work and correspondence, are Parshall & Rowe (1994), Parshall (1998; 2006). An earlier biographical account is in Macfarlane (1916). Sylvester's work on applied mathematics, which is less important, is described by Grattan-Guinness (2001).

The theory of *quaternions*, created by William Rowan Hamilton, was a novel algebraic system that promised to provide a natural language for much of mathematical physics. An early enthusiast was Peter Guthrie Tait, who devoted several papers and expository treatises to the topic. Tait's work was notable for his employment of quaternions to recast, in more compact form, the known equations of many examples from physics. In his *Treatise on Electricity and Magnetism*, James Clerk Maxwell also briefly gave a quaternion reformulation of his electromagnetic equations; and it was through Tait, his friend and former school classmate, that Maxwell became interested in this approach. Tait's far-from-elementary *Elementary Treatise on Quaternions* of 1867 was republished in several later editions, and translated into both German and French. A more elementary work, *Introduction to Quaternions* (1873 and two later editions), was a joint publication by Tait and his elderly Edinburgh colleague Philip Kelland. Most of this was written by Kelland who, in the book's preface, paid warm tribute to Tait, who "being my pupil in youth is my teacher in riper years. . . ."

Tait, the most enthusiastic user and populariser of quaternions, was also a noted polemicist, vigorously debating with those who doubted the importance of the theory. William Thomson was not a convert, either to quaternions or to the later vector calculus that displaced them. They nowhere appear in Thomson's and Tait's *Treatise of Natural Philosophy*, despite Tait's enthusiasm, because Thomson steadfastly maintained that neither formulation brought any real advantages—a view not shared by present-day scientists.[660]

Augustus De Morgan and Arthur Cayley, however, were much interested in the new algebraic structure; but Cayley and Tait disagreed over *why* quaternions were important. For Tait, their main importance was as a new compact language for widespread scientific applications. Cayley had little interest in what he saw as mere abbreviation of previously cumbersome equations; rather, he was drawn to quaternions as an interesting algebraic concept of pure mathematics, with novel properties that invited exploration and generalisation.[661] William Kingdon Clifford (2nd, 1867) also contributed related work, proposing a generalisation called "biquaternions" that he used to examine geometrical properties of curved spaces. In an 1870 work *On the Space Theory of Matter*, he proposed that both energy and matter may be regarded as types of curvature of space: similar ideas were later to form the basis of Einstein's "General Theory of Relativity".

---

[660] The protracted arguments over the relative merits of quaternions and vectors are well documented by Crowe (1985).

[661] Crowe (1985), Ch.6.

Enthusiasm for Hamilton's quaternions waned after the development in the 1890s of the more streamlined notation of *vector calculus* by Oliver Heaviside and J. Willard Gibbs. The vector calculus, even more than quaternions, imparted new mathematical elegance and conciseness to many of the results and equations of fluid mechanics, elasticity and electromagnetism. A largely unsung precursor of this theory is the work of another of our wranglers, Matthew O'Brien (3rd, 1838). O'Brien's ideas on vector-like formulations of physical and mechanical problems evolved in a series of nine papers, published between 1847 and 1852 in the *Philosophical Magazine*, the *Transactions of the Cambridge Philosophical Society*, and the *Philosophical Transactions of the Royal Society of London*. He did not entirely anticipate the later work of Gibbs and Heaviside, because some aspects of his theories were unsatisfactory; but he deserved more credit than he received for the attempt.[662]

Mathematical logic, using algebraic symbolism to denote logical processes, was a subject largely created by George Boole and Augustus De Morgan. Boole's *The Mathematical Analysis of Logic* (1847) and *An Introduction to the Laws of Thought* (1854), and De Morgan's *Formal Logic* (1847) and several papers in journals, developed the laws of *Boolean Algebra* and related algebraic structures.[663] William Rowan Hamilton and Stanley Jevons were interested critics of their work; and Hamilton made great contributions to the not-unrelated subject of graph theory. A close follower and populariser of the works of Boole was John Venn (6th, 1857), whose *Symbolic Logic* was published in 1881. It was he who developed the useful visual aid of *Venn Diagrams* for intersecting sets of objects.[664]

This is not the place to discuss the many outstanding discoveries of continental mathematicians at this time; but it is pertinent to note that there were still whole areas of pure mathematics that remained virtually untouched by British researchers. One such was the theory of functions of a complex variable, now a cornerstone of analysis: a recent historical survey of complex function theory between 1780 and 1900 mentions not a single British contribution.[665] British interest in complex variable theory developed only from the 1860s, when its usefulness for solving potential-flow problems in

662 It seems relevant that, before he attended Cambridge University, O'Brien studied at Trinity College, Dublin, where he certainly met and was perhaps taught by William Rowan Hamilton. Full references to O'Brien's work are in Crowe (1985), p.108, note 92.

663 Panteki (2003).

664 The simplest Venn Diagrams are familiar to all who, since the 1970s, studied at school the so-called "new maths" of set theory.

665 Bottazzini (2003).

hydrodynamics came to be exploited. The continental theory was finally introduced to Cambridge by Andrew R. Forsyth (1st, 1881) in his 1893 *Theory of Functions*.

A leading exponent of complex variable theory in hydrodynamics was William Burnside (2nd equal, 1875). He also wrote the first English treatise on group theory, and made numerous important contributions to that subject. The so-called "Burnside Problem" is still an area of active research in group theory.

Other British pure mathematicians who deserve mention include Henry J.S. Smith, Bartholomew Price and Charles Lutwidge Dodgson at Oxford. The first was a fellow of Balliol College from 1849, and Savilian Professor of Geometry from 1860 to 1883: he wrote mainly on number theory, elliptic functions and geometry. The second taught mathematics and then became Sedleian Professor of Natural Philosophy during 1853–98: his major mathematical work was a four-volume *Treatise on Infinitesimal Calculus* (1852–60). The last, Dodgson, better known as "Lewis Carroll" the author of *Alice's Adventures in Wonderland*, wrote texts on symbolic logic, determinants and geometry. In addition, Robert Richard Anstice, a Hertfordshire curate who had studied at Oxford's Christ Church College, published worthy papers on combinatorics.[666]

At University College, London, and later at the Royal Naval College, Greenwich, Thomas Archer Hirst pursued researches in geometry and translated continental works. Perhaps more valuable were the links that he maintained with leading overseas mathematicians. While a student in Germany, he had worked with Wilhelm Weber and met Gauss and Dirichlet; in Paris, he became friends with Chasles, Poinsot and Liouville; and later he was visited in London by Felix Klein and Chebyshev. Thereby, he brought a new international awareness to the London mathematical scene.

Probability, Statistics and Applications

From about 1860, a strong tradition was established in England on the theory and applications of statistics. The dominant figures were Francis Galton, James Clerk Maxwell, Francis Ysidro Edgworth, Karl Pearson, George Udny Yule and Ronald Aylmer Fisher. Galton, Maxwell, Pearson and Fisher were all Cambridge graduates, and more minor roles were performed by four other Cambridge wranglers of our period, R.L. Ellis, R. Campbell, J. Venn and

[666] See, for example, Fauvel, Flood & Wilson (2000).

H.W. Watson. The statistically based work of Maxwell and Watson on the kinetic theory of gases has already been mentioned. The others developed pioneering applications of statistics to biology, genetics and the social sciences.

Galton was a private scholar with private means who, like Quetelet before him, explored a wide range of biological and human applications. These included the transmission of characteristics from one generation to the next, from the size of sweet-peas to the heights of parents and children, and "hereditary genius" in "distinguished families". His works include *Hereditary Genius: An Inquiry into Its Laws and Consequences* (1869), *Natural Inheritance* (1889) and *Finger Prints* (1892). One of his main advances was the idea of *correlation*, which allows determination of the extent to which two different properties of sampled objects or individuals are related or independent. Among many other activities, he pioneered the use of statistical methods to prepare weather charts for newspapers. He coined the word "eugenics" to describe improvement of the human race by selective breeding: late in life, he controversially promoted this as a political ideal, suggesting positive incentives such as tax benefits to encourage intelligent parents to have large families. (But Galton himself remained unmarried and had no children.) His ideas sparked considerable interest at home and abroad and many "Eugenics Societies" were founded.[667] Though he had studied under William Hopkins, Galton was not a sophisticated mathematician, and he several times enlisted the aid of H.W. Watson; but he had a passion, even an obsession, for counting, and he developed new statistical methods in novel areas.

Galton's generous bequest to University College, London established the college as the major centre for applied statistics. There, Karl Pearson (3rd, 1879) was the first Galton Professor of Eugenics and R.A. Fisher (B.A. 1912) the second, while Yule worked for a time as Pearson's assistant. Pearson was a better mathematician than Galton, and a prolific writer with enormous energy. In 1901, the two had collaborated with W.F.R. Weldon to found the journal *Biometrika*, then the only, and still the major, journal in its field. (Weldon was also a Cambridge graduate, with a first class in the Natural Science Tripos of 1881.) Before taking up the Galton Professorship, Pearson had earlier proved himself a popular teacher as University College's Goldsmid Professor of Applied Mathematics and Mechanics; and his *Grammar of Science* (1892) was a widely read and wide-ranging work on the philosophy of

---

667 But none foresaw the later Nazi atrocities in pursuit of such an aim, that have discredited the concept.

science.[668] Both Pearson and Fisher shared Galton's vision of eugenics: their work explored the extent to which human characteristics were inherited, and how great was the influence of environment (briefly paraphrased as "nature versus nurture"). Thereby, they established the fields of biometrics and human genetics, and they pioneered several statistical methods that remain in common use.

Florence Nightingale, the nursing heroine of the Crimean War, applied statistics to mortality rates in military hospitals and so established the need for improved hygiene and sanitation. She had been a private pupil of J.J. Sylvester, and in 1858 was the first woman to be elected a fellow of the Royal Statistical Society.

F.Y. Edgeworth, a distant relative of Galton, corresponded with the older man about his work: he refined Galton's insight that the total population of a normal distribution may be decomposed into subsets of the total population, each with its own different normal distribution. He also wrote on regression and correlation, with particular applications to social and economic topics. While at King's College London, he published his major book *Mathematical Psychics: An Essay on the Application of Mathematics to the Moral Sciences* (1881). Despite his lack of formal mathematical education, this book shows his familiarity with the older French work on probability, with recent writings on mathematical physics by Poisson, Thomson, Tait and Maxwell, with work on the "psychophysics" of perception by Helmholtz and others, and on the mathematical economics of his friend William Stanley Jevons.

Alfred Marshall (2nd, 1865) was another who applied mathematics and statistics to economics: his several works include *The Principles of Economics* (1890). Among other Cambridge wranglers, John Venn wrote on *The Logic of Chance* (1866) with a third edition of 1888, and R.L. Ellis wrote papers on probability and the method of least squares. Robert Campbell (14th, 1854) published only one scientific paper, in 1859, but a significant one on the degree of regularity of statistical data.[669] By the late nineteenth century, statistical methods were in regular use in fields as diverse as meteorology, astronomy, biometrics, medicine, economics, psychology and actuarial science: in fact,

---

[668] In the words of a biographer, "Pearson was responsible for almost single-handedly establishing the modern discipline of mathematical statistics, including the invention of a number of essential statistical techniques, most notably the chi-square test for goodness of fit and the product moment method of calculating the correlation coefficient": Woiack (2004).

[669] Stigler (1986), pp.226–229. Campbell was a Scot previously educated at Edinburgh Academy and Edinburgh University, and pursued a successful legal career while remaining a fellow of Trinity Hall from 1854 to 1867.

wherever large amounts of numerical data could be gathered and analysed.[670]

Engineering and Technology

Very few wranglers of this time had any professional interest in applying science to technology. Many probably considered it *infra dig*. The main exceptions are William Thomson's electrical work, which had a strong engineering component; Francis Bashforth's studies on ballistics; and Archibald Smith's and Thomson's work on ships' compasses. The work of Bashforth, Smith and Thomson has already been mentioned. To them should be added Thomas Main of the Royal Naval College, Portsmouth, joint author with Thomas Brown of *The Marine Steam Engine* (1849), and James Henry Cotterill (19th, 1863). During 1866–71, Cotterill was a lecturer and later Vice-Principal at London's Royal School of Naval Architecture, and then became Professor of Applied Mechanics at the Royal Naval College, Greenwich. He was unusual in having trained as an engineer, with the leading firm of Fairbairn & Sons, before enrolling as a student at Cambridge. Like Main, he published a work on the steam engine, and he was Vice-President of the Institute of Naval Architects from 1905 until 1922.

No high Cambridge wrangler except Main and Cotterill was involved with ship design, despite its importance. But John Scott Russell, educated at no fewer than three Scottish universities, and Isambard Kingdom Brunel, educated at none, led the field in designing and building iron ships, including the mammoth *Great Eastern*. Among other British workers, William Froude researched the resistance and stability of ships, and W.J.M. Rankine and his Glasgow colleagues wrote informatively on *Shipbuilding Theoretical and Practical* (1866).[671]

William Thomson's involvement with the Atlantic telegraph cable project made him a household name and earned him a substantial fortune. This was the most ambitious, and one of the most useful, technological achievements of his generation. In it, he brilliantly—and very unusually—combined fundamental physical research with its implementation in a spectacular engineering venture. Following its success in 1866, he deservedly gained fame,

[670] Further details are in Stigler (1986), and Part 10 of Grattan-Guinness (1994).

[671] William Froude (1810–79) graduated at Oxford in 1832 with first class honours in mathematics, and worked for a time as an engineer with Brunel. Most of his experiments were conducted in a towing tank specially constructed by the Admiralty near his home at Torquay: this work influenced the design of a new generation of warships.

wealth and a knighthood. An earlier expensive failure had operated for only a few days. Together with Fleeming Jenkin, an electrical engineer who became Professor of Engineering at Edinburgh, Thomson got involved in designing its replacement. With the help of his students, Thomson thoroughly investigated the conductive properties of copper wire. He concluded that the previous failed cable had been too thin; that both the copper wire and reinforced gutta percha insulation had been of insufficient quality; and that the cable had been subjected to too large currents. He devised new sensitive measuring instruments to record very small currents, and he advised on the construction of thicker, and better insulated, cables.

The only ship large enough to lay the new cable was Brunel's and Scott Russell's *Great Eastern*. After its conversion to a cable-layer, the mission was triumphantly accomplished at the second attempt in 1866. From that time, communications between Europe and America were revolutionised: only a few years previously, news of the assassination of President Abraham Lincoln had taken twelve days to reach the English newspapers.[672]

Thomson's other engineering ventures also met with commercial success. He held many patents for electrical instruments, a siphon telegraph recorder, his ship's compass and a sounding apparatus for measuring depths at sea; and most were manufactured in his own factory, Kelvin and James White Ltd. Thomson's passion for the sea and his new-found wealth led him (after the death of his invalid first wife, Margaret) to acquire in 1870 a 126-ton schooner-yacht which became his summer home. He and his crew undertook many voyages, often to the south coast of England but also to farther destinations such as Lisbon, Madeira, and Gibraltar. He welcomed many scientific visitors on board, and there he had his study and conducted experiments, far from the pressures and distractions of Glasgow University. The most distinguished of his guests was Hermann Helmholtz, who had earlier visited P.G. Tait at his golfing home-from-home at St Andrews.[673]

The success of Samuel Laing (2nd, 1832) as managing director of the London, Brighton & South Coast Railway Company owed more to administrative, legal and financial acumen than to technological knowledge. Nevertheless, under his direction, the Company pioneered electric lighting and other comforts in their carriages. Another who conducted electrical research was Walter Baily (2nd, 1860), who invented the two-phase electric motor and other instruments.

[672] An interesting account of the early cable-laying adventures is Cookson (2003).

[673] On Thomson' s engineering and sailing, see Smith & Wise (1989), Ch.19–22.

Some other mechanical studies deserve mention, for they provided important tools of engineering design. Both W.J. Macquorn Rankine and James Clerk Maxwell were interested in the graphical representation of forces within "frame structures" such as those made from scaffolding poles or girders. Maxwell's "reciprocal figures" effectively gave a visual solution, and his method was soon used by practising engineers. Likewise, in the kinematics of linkages, better ways were found for transforming rotary motion into straight-line motion, and *vice versa*. The relatively crude mechanism first invented by James Watt for his steam engine in 1784 was elegantly transformed into simple arrays of linked and hinged rods. Such advances originated in France and Russia: surprisingly, from among our wranglers, it was the mainly pure mathematicians J.J. Sylvester and Arthur Cayley who considered this topic. Finally, in early precursors of what came to be called *control theory*, G.B. Airy, J.C. Maxwell and E.J. Routh all wrote on the action of governors to maintain near-constant speeds of rotation of shafts and magnetic coils.[674]

It is also appropriate to record the activities of the industrial entrepreneur William Cavendish (2nd, 1829), seventh Duke of Devonshire. Inheriting vast lands but substantial debts on the death of his father, the sixth Duke, he set out to recover the family fortune by judicious investment in major manufacturing projects. His business interests ranged from Buxton water to iron and steel, railways, shipping and shipbuilding, and jute manufacture. His activities changed the face of several English towns, some for better and some for worse. His iron and steel works created the industrial town of Barrow-in-Furness, but this later suffered miserably from the financial collapse of the steel industry. He invested heavily in Eastbourne, turning it into England's most fashionable resort, and he transformed Cambridge University and Owen's College, Manchester by generous donations.

During 1871–74, he chaired a Royal Commission on scientific instruction and the advancement of science, and personally founded and funded the Cavendish Laboratory in 1874 in demonstration of his commitment. (The Laboratory is named not after the donor himself, but after his family, thereby honouring, somewhat indirectly, his ancestor Henry Cavendish.) Because of the huge losses incurred by the collapse of the Barrow enterprise, William Cavendish died leaving even larger debts than his father had done; but his eldest son, the eighth Duke, was up to the task of recouping them.

674 Grattan-Guinness (1994), v.2, pp.987–1005.

13.
Postscript

We have seen how Cambridge University, at a low intellectual ebb at the start of the early nineteenth century, underwent a revival that by the 1850s established it as the pre-eminent British university for mathematics and its applications. This revival involved several distinct processes. The first was criticism from outside Cambridge, and particularly from Edinburgh, of the old-fashioned mathematical instruction that was offered, and of the poor level of understanding in Britain of recent (and not so recent) continental advances. There were also calls for more general reforms from anxious parents and disaffected former students, who accused the University and colleges of neglecting their duties.

The next advance was the adoption of textbooks on trigonometry and astronomy written by Robert Woodhouse; and the student-driven attempt, by the short-lived Analytical Society, to modernise the mathematical syllabus and to foster analytical research. The subsequent election to college fellowships of two of these students, George Peacock and Richard Gwatkin, enabled them, as Tripos moderators and examiners, to introduce the continental notation of the calculus into the examinations.

The third stage was the role of G.B. Airy, a student of Peacock who went on to become a fellow and then a professor. Airy's lectures and his *Mathematical Tracts*, influenced by the French *savants*, emphasised the use of higher analysis to tackle physical problems from astronomy, the "figure of the Earth", optics and hydrodynamics. Thereby, the strong, and continuing, Cambridge emphasis on applications of mathematics was firmly established.

The successful incorporation of such advanced material into the Tripos examinations could be accomplished only because suitable teaching was available to the students. But the many complaints of disorganisation, negligence, incompetence, indolence and worse, reveal that official instruction in the colleges was woefully inadequate (though Trinity and St John's were less guilty than the smaller colleges). Instead, the advances were driven by the private tutors and most illustriously William Hopkins, who nominally operated outside the official university system, but were in fact an indispensable part of it.

However, though the colleges did not deliver adequate teaching, they importantly provided the ablest students with strong incentives to study: to the winners, they offered the rich rewards of college fellowships and, after a few years, Church livings. As a result, the Tripos examinations became highly competitive: by 1840 or so, top wranglers were accorded high prestige throughout the United Kingdom. Even those who chose neither to stay on in Cambridge, nor to enter the service of the Church, were well placed to find rewarding employment in other universities and colleges or the law.

After this modernisation of the mathematical syllabus and implementation of a competitive and well-rewarded examination system, the next stage was reform of the University and Colleges. But those intent on retaining the long-established privileges of fellows and professors, along with the pre-eminent position of the Church of England, at first found it easy to oppose internal dissent and to ignore external criticism. The central administration of the University was weak and the Colleges (particularly their Heads) were strong; any member of the Caput could veto proposals made to Senate; and the voting of Senate itself was usually reactionary. Only when threatened with Government intervention did reforms finally begin in the late 1840s. Events before, during and after the Royal Commission of 1850–52 were summarised in Chapter 4: key roles in bringing change were played by George Peacock, William Whewell and Henry Philpott, and the views of William Hopkins on the teaching of mathematics carried considerable weight. Eventually, access to University degrees was widened by dropping religious tests for students; new Tripos subjects were introduced; college fellows were allowed to marry and most were no longer subject to religious tests. At last, but not until the 1880s, new University Lectureships were created and an effective system of instruction reduced the need for private tuition.

The final strand that established Cambridge's eminence was the creation of a strong research tradition in the applications of mathematics to physics and astronomy. Following Airy and Green, the influence of G.G. Stokes was immense. His lectures inspired and enthused generations of students; his tireless work for the Royal Society of London as Secretary and editor of its journals, and his personal research in hydrodynamics and optics, established new standards of precision and excellence. The high research calibre of Stokes' fellow-professors John Couch Adams in astronomy and Arthur Cayley in pure mathematics also did much for their respective subjects, though they were less influential as teachers. Equally fine, and more widely original, research was conducted in Glasgow by William Thomson; and notable work was done by Peter Guthrie Tait in Edinburgh. Both had studied at Cambridge after first attending Scottish universities, and Thomson retained close links with Cambridge through his friendship and regular correspondence with, and occasional visits to, G.G. Stokes. The contributions of other Scottish and Irish scholars in Cambridge, such as Gregory, Murphy, O'Brien, Smith and Steele, were also noteworthy.

In contrast with Glasgow and Edinburgh, Cambridge offered few experimental facilities for physical research; and Cambridge's reputation in engineering, chemistry and medicine remained low. But the lack of a physics laboratory was addressed in brilliant fashion by the founding of the Cavendish Laboratory through the generosity of William Cavendish, Duke of Devonshire, and by the appointment of James Clerk Maxwell as first Cavendish Professor. The physical and intellectual structures that supported the mathematical and physical endeavors of future generations were now in place.

Most of these momentous changes took place during the tutoring career of William Hopkins, which lasted from around 1828 until 1860, and many mentioned above were his pupils. In the previous chapters, we outlined his career and those of many of his top students. His true legacy is not his own research, but his guidance and inspiration of so many who went on to do great things. Though some complained of his severe demands, they received a training that was the best of its day.[675]

We saw in preceding chapters how nineteenth-century British science interacted with religious belief, and forced reinterpretation of biblical texts. The scientific tradition had for centuries been strongly imbued with the "doctrine of intelligent design". As expressed by Isaac Newton in his *Principia* (1687), "This most elegant system of the sun, planets, and comets could not have arisen without the design and dominion of an intelligent and powerful being." And Newton's most brilliant follower, Colin Maclaurin of Edinburgh University, believed that the chief value of natural philosophy was to lay "a sure foundation for natural religion and moral philosophy": to understand

---

[675] Though the Cambridge Mathematical Tripos is no longer conducted as an intense competition for top places, its present-day demands remain daunting. A recent Cambridge mathematics graduate, Tina Harris (2003) wrote that:

> The Mathematical Tripos tests your love for Maths in much the same way as a child may test its parents' love: by being difficult. When I first arrived in Cambridge, every Maths student I spoke to said they were mad about Maths; this soon changed. There were times in the first term when I struggled so much with the work that I began to question whether I had ever really liked Maths. Gradually I got used to the style of work and realised that it wasn't the Maths that I didn't like, but the way that the course forced me to limit the amount of time I spent on each examples sheet. Cambridge was the first time in my life where it had been impossible to finish everything. . . .

the physical universe, mathematics was "the instrument, by which alone the machinery of a work, made with so much art, could be unfolded."[676]

In contrast, by the early nineteenth century, when the Emperor Napoleon Bonaparte commented that he could find no mention of God in Laplace's *Mécanique Céleste*, Laplace famously and perhaps apocryphally replied that he had had "no need of that hypothesis." This view was certainly shared by some British scientists in Victorian times, particularly the physicist John Tyndall, the botanist Joseph Hooker, the biologist Thomas Huxley and the philosopher Herbert Spencer. For a time they met as members of the "X Club", a small dining and debating group: Tyndall was a self-confessed "materialist" and Huxley is said to have invented the term "agnostic" to describe his position. But these views were rejected by most of the Cambridge-educated scientific fraternity, who held that science and religious belief were inextricable, and needed to be reconciled. Indeed, the attitudes of Stokes, Thomson, Hopkins *et al.* on "intelligent design" were not far distant from those of Newton and Maclaurin.

They viewed the physical laws governing the Universe as fixed by God at the Creation: it was the scientists' goal to uncover these laws, and so better to comprehend the Supreme Intelligence that made them. The "clockwork of the heavens" revealed by astronomy and mathematics exemplified the beauty and perfection of God's works. And reinterpretations of Biblical texts in the light of new science gave a fuller understanding of the Word of God. Darwin and Wallace had proposed a new natural law that did not require Divine intervention to create new biological species; but the Cambridge scientists mostly rejected this as unproven and probably inadequate. Though accepting that it contained some degree of truth, they preferred to believe in occasional Divine intervention to nudge evolution in the "right" direction.

This idea, now sometimes called "God of the gaps", is supported by few present-day theologians.[677] Yet many scientists remain practising Christians, just as there are many who subscribe to other faiths or to none. For many, religion provides a necessary moral and spiritual framework for their lives; but Biblical accounts of physical events, past and present, have been reinterpreted (often as myth or metaphor) so as to present no serious conflict with well-established scientific facts. Key supernatural beliefs of Christianity, most importantly the Immaculate Conception of the Virgin Mary and Christ's Resurrection, are accepted as acts of faith that can neither be proved nor disproved. For a Christian, it is not inconsistent with science to accept the

[676] See Grabiner (2004).

[677] See, for example, Alexander (2001).

existence of a Supreme Intelligence as the creator of everything: such a Being could, if He chose, perform miracles that violate the observed laws of science. But, by definition, miracles hardly ever happen, and they have no place in the business and discourse of modern science.[678]

The once-heretical views of Bishop William Colenso would now hardly raise an eyebrow among liberal theologians. But relations among the various churches of the Anglican Congregation are today as problematic as those between the factions of the Church of England during the nineteenth century. In particular, major confrontations have occurred between, on the one side, the ultra-liberal Anglican Church in the United States and liberals within the Church of England, and, on the other, the more conservative African churches and some English conservatives. Particularly bitter have been the debates about the eligibility of women and homosexuals as priests and bishops. On such issues, the African churches are far closer to the missionaries who brought Christianity to that continent, than to present-day liberals.

Some of the most dogmatic opinions expressed during the religious debates of the nineteenth century are still rehearsed by today's conservative Christian fundamentalists and Creationists. But, unlike Stokes, Thomson, Hopkins, Goodwin, Pratt and others studied here, most of the modern adherents to such views ignore or deny science, rather than try to reconcile it with their religious beliefs. Like the more extreme members of the early Victoria Institute, they instinctively reject Darwinism, preferring the doctrine of "intelligent design". And many accept the literal truth of the Bible regarding the Creation and much else besides, ignoring all evidence to the contrary and also the interpretations of modern theologians. Until recently, the attitude of most scientists to such fundamentalists has been to ignore them, just as they ignore science. But such groups are acquiring political power, not only in the United States but also in Britain; and their influence on school education in some districts is already strong. Discredited in recent academic studies that draw attention to the threats they pose, these are people beyond rational persuasion.[679]

---

678 However, in recent decades the Roman Catholic Church has canonised more saints than in any similar period of its history, with "evidence" of miracles required in each case.

679 See, for instance, Forrest & Gross (2004); Shanks (2004). The Creationist movement in the United States has powerful financial backing. For example, in Petersburg, Kentucky a new Creationist natural history museum *cum* theme park is a lavish visitor attraction, designed to appeal to children and families, and peddling demonstrable scientific untruths. (Of course, religious fundamentalism and fanaticism are manifest in other religions, and are even more dangerous: but they are unconnected with this work.)

Christianity has long been allied with trade and the expansion of empires. The propagation of the Christian gospel in foreign lands was closely intertwined with the growth of capitalism. David Livingstone believed that the conversion of Africans to Christianity would only be achieved if the material benefits brought by trade were also apparent. And much warfare and oppression in India was justified on the grounds that Anglification would in the long run bring material prosperity to the people, along with their conversion to the Christian religion. It cannot be denied that the British Empire brought education and technological advances to its domains. Equally, it cannot be denied that it was Britain, and the many British planters and entrepreneurs, who benefited most from the fruits of Empire: but at the time this was regarded as a natural law of capitalism. Andrew Carnegie, Scottish-born arch-capitalist, American steel magnate and charitable benefactor, believed that civilization improved only through financial competition, and that the great inequality of rich and poor must be accepted as essential to human progress. In fact, the struggle between businesses for survival and ascendancy resembled that of Darwin's species.[680]

One characteristic of intellectual life in Britain in the mid- to late-nineteenth century was a certain coherence of views about society and its aims. Though there were bitter arguments and divergences of opinion, especially where religion was concerned, the ground on which debates were conducted was firmer than it is today. There was a wide consensus supporting Christian missionary activity abroad, and the economic expansion of the Empire, by force if necessary. The "British way of life" was a well-defined concept, at least for the middle and upper classes; and many of them felt a charitable duty to help those less fortunate than themselves.

The university studies of the educated classes established a common area of knowledge, and associated intellectual values, that could be assumed in intelligent, well-informed conversations: a common core that all educated gentlemen (and some ladies) would, or should, know. The "liberal education" of Cambridge ensured that the élite were fairly well-versed in the Classics, in aspects of Christian doctrine, and in mathematics and natural philosophy. Oxford graduates usually had less knowledge of mathematics and natural philosophy, but had studied formal logic instead. In Scotland, university studies ranged more widely, but perhaps more superficially, over mathematics, natural philosophy, moral philosophy, logic and metaphysics, with religious studies postponed to a postgraduate degree. Though different, these various educational systems were coherent, producing graduates of greater

680 See, e.g. Alexander (2001), p.207.

or lesser ability, but each with a clear concept of what education should be about. Universities had few doubts as to which subjects should be taught; and methodological approaches to subjects not part of the main curricula were also fixed by reference to these studies. Few doubted the inherent value of what was studied: to admit to ignorance of Latin or the rudiments of mathematics was to admit to a personal deficiency worthy of shame.

Though he may have been unable to follow advanced mathematics, the typical well-educated man took an interest in recent developments in the sciences. These were part of his culture, not the abstruse domain of a few specialists. Though the inaccessibility of mathematics presented a problem to many, there was a widely recognised obligation to support the subject as an important intellectual discipline to which Britain had made major contributions. The 1850–52 Commission of Enquiry into Cambridge University defended the central place of mathematics as part of a liberal education in the following terms: since the days of Isaac Barrow, Isaac Newton and Roger Cotes, Cambridge had been looked up to as

> the seat of abstract science in this country. . . . On the importance of such studies it is impossible to dwell too strongly, whether . . . as a discipline for the mind, or to the magnificent results to which their pursuit has led, and which have influenced the whole character of modern civilization. While however, it is impossible not to feel that the glory of the country itself is intimately bound up with our national progress in this direction, it is equally certain that Mathematical science, as such, is not that department of human pursuit which has ever claimed a large share of human sympathy when placed in competition with those in which excellence is more easily appreciated. What the vulgar does not accord it is necessary that the more enlightened should supply in the way of motive for entering on pursuits which have apparently little attraction in themselves.[681]

William Hopkins was not alone in associating mathematical achievement with a well-disciplined mind and high moral values. For such reasons, mathematics was a compulsory part of the education provided at most universities and colleges.

Yet divisions within mathematics were becoming apparent, as the sheer extent of the subject grew beyond the comprehension of any one individual. Pure and applied mathematics were drifting apart, and hostilities were starting to appear. In 1853, the *Royal Commission Report* had questioned the empha-

[681] *Rept.* 1852, p.105.

sis in the Tripos on higher analysis, that was needed mostly for physical applications. In 1866, the Board of Mathematical Studies debated G.B. Airy's criticisms of the *lack* of physical applications and it restored topics that had previously been dropped. At the same time, Arthur Cayley vigorously defended pure mathematics against Airy's attack on "useless algebra". But William Thomson, preoccupied with his electrical researches, wished: "Oh, that the CAYLEYS would devote what skill they have to such things instead of to pieces of algebra which possibly interest four people in the world. . . . It is really too bad that they don't take their part in the advancement of the world."[682]

Nowadays, the situation is very different and very paradoxical. Progress in mathematics and physics advances ever more rapidly, and affects everyday life more markedly, than at any time in history. But the general level of knowledge about these subjects, or any other branch of science, is very low indeed. No longer are mathematics and physics (or rather "natural philosophy") regarded as indispensable parts of broad intellectual culture. Each area of science is now a domain of narrow specialisation: it is nearly as difficult for a physicist or mathematician to understand the work of a biologist or chemist as it would be for a musicologist or an expert in French mediaeval poetry. Even within mathematics itself, communication across subdivisions is hampered by specialised language and concepts. The advance of technical knowledge has formed many barriers that are hard to cross, despite the valiant efforts of a few writers of what has become known as "popular science".

Furthermore, in contrast with the mid-nineteenth century, there is no longer a common core of knowledge, nor a consensus on intellectual and moral ideals, to inform popular debate. The public pronouncements of politicians on scientific issues are necessarily devoid of technical information (except when obfuscation is deliberate), and the extent of their own understanding is unclear.[683] The location of a new nuclear reactor (or not building one at all), the ethics of genetic modification of plants and animals (including humans), the training and recruitment of hospital staff, the funding of expensive projects in space research and elementary particle physics, are all topics that require a high degree of technical knowledge. But public debate about such matters is usually conducted in an emotional, confrontational or polemical way, rather than a rational and well-informed one. Decision-making is instead filtered through bureaucrats, advisory panels, official submissions from interested bodies, select Parliamentary Committees and so forth. Televi-

---

682 Thomson to H. Helmholtz, 1864; in Thompson (1910), v.1, p.433.

683 How many Members of Parliament can solve even a quadratic equation? Does it matter?

sion, which might have become an effective means of public instruction and communication, is instead largely the "opium of the people", prone to over-simplification and sensationalism.

The British universities, too, are in a strange state. Now hugely expanded in number and size, few have maintained any central core of study (though a few of the old "new" universities of the 1960s still have a common foundation year). In most English universities, specialisation begins in first year, with students admitted to study a specific degree course in a named subject.[684] In contrast, admission to most Scottish universities is by faculty, and students retain some flexibility of choice until a later stage.[685] But, under increasing financial pressure, universities now add or drop degree subjects in line with their profitability. And education that is primarily driven by student choice, at the entrant age of eighteen, produces some strange results.[686]

One of the most worrying for the nation's future is the decline in numbers of applicants for engineering, and for the core sciences of mathematics, physics and chemistry. Uneconomic—that is to say, under-subscribed and unprofitable—departments in these subjects close, year on year, and the nation's intellectual and technological base is eroded. Similarly, in the Arts, there is a marked retreat from foreign language study. The universities, pursuing short-term advantage and balancing budget deficits, do not confront the wider educational and economic consequences of their actions.[687]

[684] Though not impossible, later transfer to another degree course is usually discouraged.

[685] Also, up to the 1960s, most Scottish universities retained as compulsory certain designated first-year subjects: for the M.A. degree, at least one foreign language (in some, specifically Latin) and either philosophy or mathematics.

[686] Governmental control is mainly financial; and, following controversies over departmental closures during 1970–80, the University Funding Councils that distribute Government funds have understandably become more reluctant to dictate to individual universities which subjects should be taught. "Rationalisation" is now largely left to the management of each institution, and some have acted in draconian fashion. The Funding Councils retain power to set limits, in each subject, on the number of "home" students whose places are subsidised. But if students do not apply in sufficient numbers, these limits cannot be reached, while other courses are over-subscribed.

[687] What value has an honours degree in, say, International Relations, if a graduate cannot read or converse in any language but his or her own? Or one in Classical Studies or Ancient History, if no Greek or Latin is studied? Where will all the graduates in drama, media and film studies, psychology, and the various social sciences find jobs? And is it *respectable* to offer an honours degree course in Computer Games Design (however popular and profitable), rather than embed it as a small part of Computer Science? This is a far cry from Whewell's ideal of a "Liberal Education".

In mid-nineteenth-century Cambridge, there was a vast difference in ability between the top wranglers and the lowest Junior Optimes. The situation is not dissimilar in British universities today. There is a common view that the academic standards required for an honours degree are lower today than, say, thirty years ago. There are also those who deny this, arguing that more first-class degrees indicate better teaching and learning. Statistics do not seem to support the latter view: whereas about 10% of the age group obtained British university degrees in 1970, nearly 50% now do so, and there were roughly as many first-class honours graduates in 2000 as the total number of university students in 1970. Are there really so many first-class minds nowadays? At the other extreme, many working in British universities today feel under pressure to keep failure rates low, because it is the teachers and not the students who are now blamed if a course has a substantial number of failures.[688] At the same time, nearly all students are permitted to take honours degrees (so boosting departmental numbers and income): the ordinary degree, previously a respectable if lower qualification, has virtually disappeared.

The difficulties faced by Cambridge college teachers around 1850 are still replicated in many universities around the country: only a few institutions can insist that all their entrants have very good qualifications. In many British universities, mathematics and physics students with vastly disparate entry qualifications and talents are lectured to in large classes, at a pace too slow for the best and too fast for many. Tutorial instruction is often farmed out to relatively inexperienced graduate students, while the permanent staff are burdened with heavy lecturing loads and administrative duties, and are under ever-increasing pressure to produce original research—or, rather, to obtain external grants to do so. Accordingly, the very best students are sometimes not stretched to achieve their full potential, while the poorest are out of their depth and often reluctant to seek the help they need until it is too late. And there are no private tutors to turn to.

Mathematics is an unforgiving subject in which ignorance cannot be truly hidden; but examinations can be constructed so as to reward a modicum of knowledge, when failure might previously have been the outcome. As at Cambridge in the nineteenth century, there is a vast gulf in demonstrated ability between the top and the bottom honours degrees.[689]

---

688 This is not so in most European universities, where huge classes and large failure rates are common: but these, too, bring their own problems.

689 It is perhaps unwise to generalise since anomalies occasionally occur, but a lower second class honours degree in mathematics today usually indicates a level of skill and knowledge that is just fit for school teaching, but is likely to prove inadequate for any task requiring original and accurate calculation. And a third-class degree shows little evidence of competence at all, beyond that required for university entrance.

But the future of mathematics in Cambridge, and in a few other centres in Britain, looks secure, though in many other places the outlook seems bleak. Despite all the cuts elsewhere, Cambridge University has survived and flourished. It recruits well-qualified entrant students and large numbers of postgraduates, many of the latter from overseas. Until about 1960, few British universities apart from Oxford, Cambridge and perhaps Manchester and London actively recruited postgraduate students even from among their own graduates, although a few turned up here and there. Students graduating in the 1950s who wished to embark on research work were generally advised to go to Cambridge, Oxford or overseas. This was still following the trend established in the mid-nineteenth century, when many graduates went on to Cambridge for further study and career advancement.

Though Cambridge University is notionally subject to the same financial constraints as other places with regard to Government support, it (and also Oxford) continues to be bolstered financially and numerically by the colleges, much as it was in the nineteenth century. Sheer numerical strength makes its research groups more robust than those in most other centres, which usually depend on the leadership of a very few key individuals. And Cambridge, more than any other British university except Oxford, has successfully courted private and corporate benefactors. Many of the latter are keen to be seen to be associated with Cambridge's continued high standing in research. Most spectacularly, the University has recently built a huge and luxurious new complex of buildings to house the mathematical sciences, funded by a consortium of generous donors that include several Cambridge colleges and both home and overseas benefactors. William Hopkins and his men would have been amazed by this new temple to mathematics; but, without them, it could never have come about.

Appendix

Appendix A

Green's Theorem, from Green's 1828 *Essay* (for Chapter 8)

> Let U and V be two continuous functions of the rectangular coordinates x, y, z, whose differential coefficients do not become infinite at any point within a solid body of any form whatever; then will
>
> $$\int dxdydzU\delta V + \int d\sigma U\left(\frac{dV}{dw}\right) = \int dxdydzV\delta U + \int d\sigma V\left(\frac{dU}{dw}\right);$$
>
> the triple integrals extending over the whole interior of the body, and those relative to $d\sigma$, over its surface, of which $d\sigma$ represents an element: dw being an infinitely small line perpendicular to the surface, and measured from this surface towards the interior of the body.

Here δU and δV denote the Laplacians of the functions $U(x, y, z)$ and $V(x, y, z)$: i.e.,

$$\delta U \equiv \nabla^2 U \equiv \frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2}.$$

If one of the spatial variables is absent, the corresponding "Green's Theorem in the plane" is a special case of Stokes' Theorem relating a surface integral to a line integral around its periphery. And, if one defines the vector F with components

$$V\frac{\partial U}{\partial x} - U\frac{\partial V}{\partial x}, \quad V\frac{\partial U}{\partial y} - U\frac{\partial V}{\partial y}, \quad V\frac{\partial U}{\partial z} - U\frac{\partial V}{\partial z},$$

Green's Theorem directly yields the *divergence theorem*, or *Gauss's Theorem*,

$$\int_V \nabla . F d\tau = \int_S F . dS,$$

in the notation of vector calculus.

The various integral theorems of Green, Murphy, Stokes and Thomson are surveyed by Cross (1985).

Appendix B

Table A. High wranglers graduating during 1829–56 who held Cambridge University or College appointments for more than a few years (for Chapter 9)

Henry Philpott (1st, 1829), fellow 1829–45 and Master 1845–60 of St Catharine's College; (Bishop of Worcester 1861–90);

Robert Murphy (3rd, 1829) fellow of Gonville & Caius College 1829–43 (absent after 1836);

Edward Horatio Steventon (3rd, 1830), fellow of Corpus Christi College 1832– (absent after 1841);

John Moore Heath (27th equal, 1830), fellow 1831–, assistant tutor 1833–39, and tutor 1839–44 of Trinity;

Samuel Earnshaw (1st, 1831), St John's College, successful private tutor 1831–47;

Thomas Gaskin (2nd, 1831), fellow of Jesus College 1832–42;

John Newton Peill (7th, 1831), fellow, bursar, tutor etc. of Queens' College, 1832–53;

George Edward Paget (8th, 1831), medical fellow 1832–51 of Gonville & Caius College, physician to Addenbrooke's Hospital 1839–84, Regius Professor of Physic 1872–92;

Samuel Laing (2nd, 1832), fellow 1834–41 of St John's College;

Thomas Cotterill (3rd, 1832), fellow 1834–42 of St John's College;

Henry Wilkinson Cookson (7th, 1832), fellow 1836–, tutor 1839– and Master 1847–76 of Peterhouse;

Robert Phelps (5th, 1833), fellow 1838–43 and Master 1843–90 of Sidney Sussex College;

Thomas Rawson Birks (2nd, 1834), fellow and tutor of Trinity College 1834–36, Knightsbridge Professor of Moral Philosophy 1872–83, and vicar of Holy Trinity, Cambridge 1866–77;

William Walton (8th, 1836), fellow and assistant tutor of Trinity Hall 1868–85, and private tutor;

William N. Griffin (1st, 1837), fellow of St John's College and private tutor 1837–48;

James G. Mould (2nd, 1838), fellow 1838–55 and tutor 1842–55, of Corpus Christi College;

Percival Frost (2nd, 1839), fellow of St John's College, 1839–41; mathematical lecturer at Jesus College, 1847–59, and at King's College, 1859–89; fellow of King's College 1882–98; private tutor;

Table A. *Continued*

William Collings Mathison (5th, 1839), fellow, assistant tutor and tutor 1840–68, Vice-Master 1866–68 of Trinity College;

Robert Leslie Ellis (1st, 1840), fellow 1840–49 of Trinity College;

Harvey Goodwin (2nd, 1840), fellow 1841–45 and honorary fellow 1880–91 of Gonville & Caius College; (Bishop of Carlisle 1869–91);

George Gabriel Stokes (1st, 1841), fellow, 1841–57 and 1869–1902, and Master 1902–03 of Pembroke College, Lucasian Professor of Mathematics 1849–1903;

John Sykes (3rd, 1841), fellow 1841–65 of Pembroke College;

Charles Anthony Swainson (6th, 1841), fellow 1841–52, tutor, and Master 1881–87 of Christ's College; Norrison Professor of Divinity 1864–79 and Lady Margaret Professor of Divinity 1879–87;

John Power (8th, 1841), fellow then tutor 1852–70, Master 1870–80 of Pembroke College;

Arthur Cayley (1st, 1842), fellow 1842–52 and 1875–1895, of Trinity College, Sadlerian Professor of Pure Mathematics 1863–95;

Robert Bickersteth Mayor (3rd, 1842), fellow 1845–64 of St John's College;

Frederick Fuller (4th, 1842), fellow and mathematics lecturer of Peterhouse, 1843–51, and private tutor;

John Couch Adams (1st, 1843), fellow 1843–52 of St John's College, 1853–57 of Pembroke College; Lowndean Professor of Astronomy and Geometry 1859–92, Director of the Cambridge Observatory 1861–92;

William Bonner Hopkins (2nd, 1844), fellow of Gonville & Caius College 1844–47, St Catharine's College 1847–54;

Stephen Parkinson (1st, 1845), fellow 1845–71 and 1882–89, tutor 1864–82; President 1865–89 of St John's College;

William Thomson (2nd, 1845), fellow 1845–52 and 1872–1907 of Peterhouse;

Robert Peirson (3rd, 1845), fellow 1849–55 of St John's College;

Henry Latham (18th, 1845), fellow 1847–, senior tutor 1855–85, Master 1888–1902 of Trinity Hall;

Isaac Todhunter (1st, 1848), fellow 1849–64, mathematical lecturer and senior mathematical lecturer 1852–64 of St John's College, private tutor and prolific textbook writer;

William Archer Porter (3rd, 1849), fellow 1849–, tutor 1855–56 of Peterhouse.

William H. Besant (1st, 1850) fellow of St John's College, Esquire Bedell 1866–70, college lecturer and tutor for 35 years;

Joseph Wolstenholme (3rd, 1850), fellow of Christ's College, 1852–69;

George Downing Liveing (11th, 1850), fellow 1853–60, 1880–1924 of St John's College, Professor of Chemistry 1861–1908;

Norman Macleod Ferrers (1st, 1851), fellow 1852–80 and Master 1880–1903 of Gonville and Caius College;

James Porter (9th, 1851), fellow 1853–, tutor 1866–76 and Master 1876–1900 of Peterhouse;

Table A. *Continued*

Hugh Godfray (3rd, 1852), Esquire Bedell 1854–77 (and astronomer);

Samuel George Phear (4th, 1852), fellow 1853–71 and Master 1871–95 of Emmanuel College;

Thomas Bond Sprague (1st, 1853), fellow 1853–60 of St John's College;

Charles John Newbery (3rd, 1853), fellow 1854–61 of St John's College;

Edward John Routh (1st, 1854), fellow, assistant tutor etc. of Peterhouse 1855–64, college lecturer in mathematics 1855–1904, extraordinarily successful private tutor, and writer on dynamics;

James Clerk Maxwell (2nd, 1854), fellow of Trinity College 1855–79 (absent 1856–70), Cavendish Professor of Experimental Physics 1871–79;

Charles Baron Clarke (3rd equal, 1856), fellow of Queens' College 1857–, college lecturer in mathematics 1858–65;

Augustus Vaughton Hadley (1st, 1856), fellow 1857–65 and tutor of St John's College;

John Clough Williams Ellis (3rd equal, 1856), fellow 1856–77 and tutor 1859–76 of Sidney Sussex College;

Henry Fawcett (7th, 1856), fellow of Trinity Hall 1856–84, Professor of Political Economy 1863–84;

Benjamin Theophilus Moore (8th, 1856), fellow of Pembroke College 1857–72 (mainly absent?).

References

Manuscripts and Portraits

Adams, John Couch ms.1855. Letter to J.D. Forbes, June 28. Papers of James David Forbes, msdep7, Incoming letters 1855, no.83. Special Collections, University of St Andrews Library.

Adams, John Couch ms.1858. Oaths of abjuration and allegiance. St Andrews University Library MSS; 16 & 17 Victoria. Cap: 89. Special Collections, University of St Andrews Library.

Brewster, David mss.1841; 1854. Letters to H. Brougham, 26,624 (Dec. 14, 1841); 26,677, (Mar. 4, 1854). Brougham Papers, University Coll. London Library Services, Special Collections.

Brewster, David mss.1854–58. Letters to H. Brougham, dated Feb. 1854 to Feb. 1858; 26,676–26,702. Brougham Papers, University Coll. London Library Services, Special Collections.

Challis, James ms.1854. Letter to J.D. Forbes, Mar. 10. Papers of James David Forbes, msdep7: Incoming letters 1854, no. 52. Special Collections, University of St Andrews Library.

Clarke, Charles Baron ms.1865. Letter to John(?) Porter from Calcutta, Jan. 18. Tait Papers, No.1. Cambridge University Centre for South Asian Studies.

Forbes, James D. ms.1840. Letter to W. Hopkins, March 17. Papers of James David Forbes, msdep7: Letterbook III, pp.77–78. Special Collections, University of St Andrews Library.

Forbes, James D. mss.1844; 1847c. Letters to Alicia Forbes, Sept. 27, 1844 (Incoming letters 1844, no. 52); June 1847 (Incoming letters 1847, no. 30). Papers of James David Forbes, msdep7, Special Collections, University of St Andrews Library.

Forbes, James D. ms.1845. Letter to W. Whewell, April 8. Papers of James David Forbes, msdep7, Letterbook III, pp.668–670. Special Collections, University of St Andrews Library.

Forbes, James D. ms.1846. Letter to W.H. Smyth, Dec. 2. Papers of James David Forbes, msdep7, Letterbook IV, pp.140–141. Special Collections, University of St Andrews Library.

Forbes, James D. ms.1847a. Letter to W. Thomson, Jan, 17. Papers of James David Forbes, msdep7, Letterbook IV, pp.164–167. Special Collections, University of St Andrews Library.

Forbes, James D. ms.1847b. Letter to B. Studer, July 2. Papers of James David Forbes, msdep7, Incoming letters 1847, no. 32. Special Collections, University of St Andrews Library.

Hopkins, Caroline F. mss.1871. Letters to G.G. Stokes. Stokes Correspondence. Add. 7656: H978, H979, H980. Manuscripts and University Archives, Cambridge University Library.

Hopkins, J. Ellice ms.1872. Letter to G.G. Stokes, Oct. 20, Stokes Correspondence. Add. 7656, H955. Manuscripts and University Archives, Cambridge University Library.

Hopkins, William mss.1838; 1839. Letters to James D Forbes, Feb. 11, 1838; Jan. 14, 1839. Papers of James David Forbes msdep7: Incoming letters 1839, no.3. Special Collections, University of St Andrews Library.

Hopkins, William mss.1860; 1861a,b; 1862; 1864. Letters to G.G. Stokes; 1861c Letter to E. Sabine. Stokes Correspondence. Add. 7656: H983 (Oct. 30, 1860), H986 (Mar. 15, 1861), H987 (April 17, 1861), H984 (to Sabine, April 17, 1861), H989 (Oct. 27, 1862), H990 (May 14, 1864). Manuscripts and University Archives, Cambridge University Library.

Kelland, Philip ms.1845. Letter to J.D. Forbes, June 12. Papers of James David Forbes, msdep7, Incoming letters 1845, no. 74. Special Collections, University of St Andrews Library.

Lloyd, Humphrey ms.1856. Letter to J.D. Forbes, Jan. 11. Papers of James David Forbes, msdep7, Incoming letters 1845, no. 74. Special Collections, University of St Andrews Library.

Maxwell, James Clerk mss.1851–53. Notes from Hopkins' booklets and lectures. Six notebooks. Add. MSS 7655, V.m/5–10. Manuscripts and University Archives, Cambridge University Library.

Mayo mss. Mayo Papers no.66: Minority of Maharaja of Mysore 1869–1871 (7 items). Add. Mss 7490. Lett.4, Lt. Col. Malleson to Lord Mayo, July 21, 1870; Lett.5, Chama Rajendra Wudier [sic] to Lord Mayo, Jan. 26, 1871; Lett.6, O. Burns to Lord Mayo, Feb. 15, 1871. Manuscripts and University Archives, Cambridge University Library.

Murchison, Roderick I. ms.1859. Letter to J.D. Forbes, Nov. 3. Papers of James David Forbes, msdep7, Incoming letters 1859, no. 151. Special Collections, University of St Andrews Library.

Peterhouse mss. Notes from Hopkins' booklets and lectures: hydrodynamics, optics, and astronomy by L. Ewbank, "corrected up to 1860 by F.J. Braithwaite"; "Dynamics of a Particle" (marked "Hopkins' MSS" on cover) by E.J. Routh. PET.MS.960.1–2. Peterhouse Library, Cambridge.

Romilly, Joseph mss.1818–64. Diaries of Joseph Romilly: 41 notebooks. Manuscripts and University Archives, Cambridge University Library. [Extracts published in Bury (1967) and Bury & Pickles (1994; 2000).]

Smith, Archibald ms.1834. Letter to Christina Smith, April 28. Strathclyde Regional Archives, TD1/692/2.

Smith, Archibald ms.1840. Copy of letter of May 17, 1840, sent by Susan P. Smith (of Weybridge) to Montague Butler, Master of Trinity. on Dec. 13, 1895. Pasted into Wren Library portrait album, Trinity College, Cambridge.

Stokes, George G. mss.1838–40. Notes on mechanics, hydrodynamics, sound and light, from Hopkins' booklets and lectures. Stokes Collection PA 2–24, Manuscripts and University Archives, Cambridge University Library.

Thomson, William ms.1841. Letter to James Thomson (father) Nov. 21. Add. MS 7342, T.185, Manuscripts and University Archives, Cambridge University Library.

Thomson, William mss.1842–44. Notes from Hopkins' booklets and lectures. Kelvin Collection PA 11–17, Manuscripts and University Archives, Cambridge University Library.

Whewell, William mss.1846; 1859. Letters to J.D. Forbes, Sept. 29, 1846 (Incoming letters 1846); Mar. 20 1859 (Incoming letters 1859, no.16). Papers of James David Forbes, msdep7, Special Collections, University of St Andrews Library.

Woodhouse, Robert ms.1814. Letter to Macvey Napier, May 22. Macvey Napier Corr. Add. MSS. 34,611 f. 63. British Library, London.

Wren Library album. Portraits of Hopkins' wranglers by Thomas Charles Wageman (*et al.*?). Wren Library, Trinity College, Cambridge.

Electronic Sources

Sackler Archive of Royal Society Fellows, The Royal Society of London: <www.royalsoc.ac.uk/page.asp?id=1058>

MacTutor History of Mathematics Archive, University of St Andrews: <www-history.mcs.st-andrews.ac.uk/history>

Oxford Dictionary of National Biography online: <www.oxforddnb.com>

Books and Articles

"A Graduate of Cambridge" 1836. *Letters to the English Public on the Condition, Abuses, and Capabilities of the National Universities*. No.1, 48pp. pamphlet. London: B. Fellowes.

Ackermann, Rudoph & Combe, William 1815. *A History of the University of Cambridge : Its Colleges, Halls, and Public Buildings*. 2 vols. (with 64 colour plates by various artists). London: L. Harrison and J.C. Leigh, for R. Ackermann. [Also 20 plates reproduced in: Reginald Ross Williamson 1951. *Ackermann's Cambridge*. King Penguin books no.59. London: Penguin Books.]

Adams, John C. 1846–47. "An Explanation of the Observed Irregularities of the Motion of Uranus, on the Hypothesis of a Disturbance Caused by a More Distant Planet: With a Determination of the Mass, Orbit, and Position of the Disturbing Body." *Mon. Not. Astron. Soc.* **7**: 149–152; *Mem. Astron. Soc.* **16**: 427–460.

Adams, John C. 1851. "On the Perturbations of Uranus." *Naut. Alm. (1851) Appendix*: 265–293.

Adams, John C. 1896. *The Scientific Papers of John Couch Adams*, ed. William G. Adams, with a memoir by J.W.L. Glaisher. 2 vols. Cambridge: Cambridge Univ. Press.

Airy, George Biddell 1826. *Mathematical Tracts*. Cambridge: J. Smith.

Airy George Biddell 1896. *Autobiography of Sir George Biddell Airy K.C.B. . . .* , ed. W. Airy. Cambridge: Cambridge Univ. Press.

Alexander, Denis 2001. *Rebuilding the Matrix—Science & Faith in the 21st Century*. Oxford: Lion.

Altholz, Josef 1994. *Anatomy of a Controversy: The Debate over Essays and Reviews 1860–1864*. Aldershot UK: Scolar Press; Brookfield, Vermont: Ashgate.

Anderson, Robert D. 1983. *Education and Opportunity in Victorian Scotland: Schools & Universities*. Oxford: Clarendon.

Anderson, Robert E. 1891. "Hopkins, William", *Dictionary of National Biography*. London: Smith, Elder.

Anon., signed "W." 1826. "The Cambridge University Senate-House Examination for Degrees." *London Magazine and Review*, New ser. **4** (I–IV): 289–314.

Anon. 1850. "A Few Plain Facts and Observations Relative to the Two Universities of Oxford and Cambridge by An Anxious Father," 32pp. printed pamphlet. London: J. Hatchard & Son. [Copy in Wren Library, Trinity Coll.]

Anon. 1866. "Death of William Hopkins, M.A." *The Times*, Oct. 16, 1866, p.4.

Anon. 1878. *Asylum Press Almanac* annual (continuation of *Madras Press Almanac*). Madras: William Thomas.

Anon. 1882. *History of Services of Gazetted Officers in the Civil Department Serving in the Madras Presidency*. Madras.

Anon. 1903. "Norman Macleod Ferrers, D.D., F.R.S. Master of the College, 1880–1903." (Obituary) *The Caian*, **12**: 85–92.

Anon. 1908. *The Kumbakonam College Calendar for 1908*. Madras: Government Press [copy in British Library].

[Atkinson, Solomon] 1825a. "Struggles of a Poor Student Through Cambridge, by a Senior Wrangler." *London Magazine and Review*, New ser. **1** (No. IV): 491–510.

[Atkinson, Solomon] "N.N." 1825b. "Continuation of the Struggles of a Senior Wrangler." *London Magazine and Review*, New ser. **2** (No. VI): 161–182.

[Atkinson, Solomon (attrib.)] "Cantabrigiensis" and "A.H." 1825c. "The Regrets of a Cantab." *London Magazine and Review*, New ser. **3** (No. XII): 437–466.

[Atkinson, Solomon (attrib.)] 1827. Review of *Alma Mater* . . . [by J.M.F. Wright]. *London Magazine and Review*, New ser. **7** (No. IV): 441–454.

Babbage, Charles 1830. *Reflections on the Decline of Science in England, and on Some of Its Causes*. London: for B. Fellows.

Bain, Alexander 1848. "Of a Liberal Education in General, and with Particular Reference to the Leading Studies of the University of Cambridge," 24pp. pamphlet reprinted from *The Westminster & Foreign Quarterly Review*, July. London: Waterlow & Sons.

Barff, Henry E. 1902. *A Short Historical Account of the University of Sydney*. Sydney: Angus & Robertson.

Barrow-Green, June 1999. "A Corrective to the Spirit of Too Exclusively Pure Mathematics: Robert Smith (1689–1768) and His Prizes at Cambridge University." *Annals of Science* **56**: 271–316.

Barrow-Green, June 2001. "The Advantage of Proceeding from an Author of Some Scientific Reputation: Isaac Todhunter and His Mathematical Textbooks." In Smith & Stray (2001) pp.177–203.

Barrow-Green, June 2004. "Wolstenholme, Joseph". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Barton, Sir William 1934. *The Princes of India*. London: Nisbet & Co.

Bashforth, Francis [& J.C. Adams] 1883. *An Attempt to Test the Theories of Capillary Action by Comparing the Theoretical and Measured Forms of Drops of Fluid. With an Explanation of the Method of Integration Employed in Constructing the Tables Which Give the Theoretical Forms of Such Drops, by J. C. Adams*. Cambridge.

Becher, Harvey W. 1984. "The Social Origins and Post-Graduate Careers of a Cambridge Intellectual Élite, 1830–1860." *Victorian Studies* **28**: 97–127.

Becher, Harvey W. 1991. "From Mathematics to Moral Philosophy." In Fisch & Schaffer (1991), pp.1–29.

Beckinsale, Robert P. 1973. "Hopkins, William". In *Dictionary of Scientific Biography*, ed. Charles C. Gillispie. New York: Scribners.

Bellot, H. Hale 1929. *University College London 1826–1926*. London: Univ. of London Press.

Berry, Arthur 1898. *A Short History of Astronomy from Earliest Times Through the Nineteenth Century*. London: John Murray. Reprinted New York: Dover, 1961.

Besant, Annie 1924. *Higher Education in India, Past and Present*. Convocation Address to the University of Mysore, Oct. 29, 1924. Adyar, Madras: Theosophical Publishing House.

Besant, (Sir) Walter 1902. *Autobiography of Sir Walter Besant*. London: Hutchison & Co.

Beverley, Robert M. 1833. *A Letter to His Royal Highness the Duke of Gloucester, Chancellor; on the Present Corrupt State of the University of Cambridge*, 46pp. printed pamphlet. London: J. Dinnis.

Beverley, Robert M. 1834. *Reply to Professor Sedgwick's Letter, in the "Leeds Mercury" Concerning the Present Corrupt State of the University of Cambridge*, 39pp. pamphlet. London: J. Dinnis.

Biot, Jean-Baptiste 1850. *Elementary Chapters in Astronomy from the 'Traité Élémentaire d'Astronomie Physique'* [Ch. 1–5 of 3rd edn.], edited and translated by the Rev. Harvey Goodwin. Cambridge : J. Deighton.

Birch, Alan & Macmillan, David S. (eds.) 1962. *The Sydney Scene 1788–1960*. Melbourne: Melbourne Univ. Press.

Birks, Thomas R. 1861. *The Bible and Modern Thought*. London: Religious Tract Soc.

Blackburn, Jemima 1988. *Jemima. The Paintings and Memoirs of a Victorian Lady*, edited and with an introduction by Robert Fairley. Edinburgh: Canongate.

Bottazzini, Umberto 2003. "Complex Function Theory, 1780–1900." In Hans Niels Jahnke (ed.), *A History of Analysis*, Ch.8, pp.213–359. Providence R.I. and London: American Math. Soc./London Math. Soc. History of Mathematics Series, vol.24. [Trans. and revision of 1999 German edn.]

Brewster, David 1830. "Reflections on the Decline of Science in England, and Some of Its Causes." *Quarterly Rev.*, **43** (no. 86): 305–342.

Brewster, David 1831. "Observations on the Decline of Science in England." *Edinburgh J. of Science*, new ser. **5** (no. 1): 1–16.

[Brewster, David] 1837. Review of Whewell's 'History of the Inductive Sciences'. *Edinburgh Rev.* **66**: 110–151.

Bristed, Charles Astor 1852. *Five Years in an English University*. 2 vols. New York: Putnam.

Brooke, Christopher 1985. *A History of Gonville and Caius College*. Cambridge: Boydell Press.

Bullough, Robin K. 1988. "The Wave "Par Excellence", the Solitary, Progressive Great Wave of Equilibrium of the Fluid—An Early History of the Solitary Wave." In *Solitons*, ed. M. Lakshmanan, pp.150–281. New York: Springer.

Bury, John P.T. (ed.) 1967. *Romilly's Cambridge Diary 1832–42*. Cambridge: Cambridge Univ. Press.

Bury, M.E. & Pickles, John D. (eds.) 1994. *Romilly's Cambridge Diary 1842–1847: Selected Passages from the Diary of the Rev. Joseph Romilly, Fellow of Trinity College and Registrary of the University of Cambridge*. Cambridge: Cambridgeshire Records Soc. vol. 10.

Bury, M.E. & Pickles, John D. (eds.) 2000. *Romilly's Cambridge Diary 1848–1864: Selected Passages from the Diary of the Rev. Joseph Romilly, Fellow of Trinity College and Registrary of the University of Cambridge*. Cambridge: Cambridgeshire Records Soc. vol. 14.

Butt, John 1996. *John Anderson's Legacy: The University of Strathclyde and Its Antecedents 1796–1996*. East Linton, Scotland: Tuckwell Press and Strathclyde Univ.

Cambridge University Calendar (annual). Cambridge: Deighton Bell.

Campbell, Lewis & Garnett, William 1884. *The Life of James Clerk Maxwell with Selections from His Correspondence and Occasional Writings*. New edn. abridged and revised [1st edn. 1882]. London: Macmillan.

Cannell, D. Mary 2001. *George Green: Mathematician and Physicist 1793–1841*. 2nd edn. Philadelphia: SIAM.

Cardwell, Donald S.L. 1972. *The Organisation of Science in England*. rev. edn. London: Heinemann.

Cartwright, David E. 1999. *Tides: A Scientific History*. Cambridge: Cambridge Univ. Press.

Cayley, Arthur 1889–98. *The Collected Mathematical Papers of Arthur Cayley*. 14 vols. Cambridge: Cambridge Univ. Press.

Cazenove, Dr. [J.G.] 1867. "Bishop Cotterill." *Proc. Roy. Soc. Edinburgh*, **14** (1866–67). Obituary Notices pp.151–161.

Chadwick, Owen 1959. *Mackenzie's Grave*. London: Hodder & Stoughton.

[Chambers, Robert] 1844. *Vestiges of the Natural History of Creation*. London: Churchill.

Charlton, Henry B. 1951. *Portrait of a University, 1851–1951; to Commemorate the Centenary of Manchester University*. Manchester: Manchester Univ. Press.

Checkland, Olive 1989. *Britain's Encounter with Meiji Japan, 1868–1912*. Basingstoke & London: Macmillan.

Chevallier, Temple 1836. *The Study of Mathematics as Conducive to the Development of the Intellectual Powers, with Some Remarks upon an Article in the Last Number of the Edinburgh Review*. Durham: for J.W. Parker.

Chisholm, Alec H. (ed.) c.1958. *The Australian Encyclopedia*. 10 vols. Sydney: Angus & Robertson.

Chrystal, George 1892. "Promoter's Address to Graduates of Arts, University of Edinburgh." *The Scotsman*, Edinburgh, 15 April.

Clark, John W. & Hughes, Thomas M. 1890. *The Life and Letters of the Rev. Adam Sedgwick*. 2 vols. Cambridge: Cambridge Univ. Press.

Clark, John W. 1895. "Peacock, George". In *Dictionary of National Biography*. London: Smith, Elder.

Clerke, Agnes M. (rev. Allan Chapman) 2004a. "Main, Robert". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Clerke, Agnes M. (rev. Anita McConnell) 2004b. "Pritchard, Charles". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Colenso, John W. 1841. *The Elements of Algebra, Designed for the Use of Schools*. Second edition, improved and enlarged. Cambridge: J. & J.J. Deighton, J.W. Parker; London: Longman & Co.

Colenso, John W. 1843. *Arithmetic, Designed for the Use of Schools*. London: Longman & Co.

Colenso, John W. 1846. *Euclid's Elements . . . (The Parts Read in the University of Cambridge) from the Text of Dr. Robert Simson; with Geometrical Problems for Solution by the Rev. J.W. Colenso, M.A.* London: Longman.

Colenso, John W. 1851. *Plane Trigonometry*. London: Longman.

Colenso (Bishop) John W. 1861. *St Paul's Epistle to the Romans: Newly Translated, and Explained from a Missionary Point of View*. Ekukanyeni, Natal; and Cambridge: Macmillan.

Colenso (Bishop) John W. 1862. *Pentateuch and the Book of Joshua, Critically Examined*. Ekukanyeni, Natal (part 1 only); 2 vols. London: Longman etc.

Commissioners' Report 1852. (*Report of the 1850 Royal Commission into the State of the University of Cambridge and the Colleges Thereof.*) Commissioners: J. Graham (Bishop of Chester), G. Peacock, J.F.W. Herschel, John Romilly, A. Sedgwick; Secretary: W.H. Bateson.

Cookson, Gillian 2003. *The Cable: The Wire that Changed the World*. Stroud, Gloucestershire UK: Tempus.

Corley, T.A.B. & Crilly, A.J. 2004. "Cockle, James". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

[Cotterill, Henry] 1864. *Opinion Delivered by the Bishop of Grahamstown as Assessor in the Trial of the Right Rev. J. W. Colenso*, December 14th, 1863. 45pp. London: Bell & Daldy; Cambridge: Deighton, Bell & Co.

Cox, George W. 1888. *Life of John William Colenso*, *Bishop of Natal*. 2 vols. London: W. Ridgway.

Craik, Alex D.D. 1998. "John West in Scotland and Jamaica." *Historia Mathematica* **25**: 29–74.

Craik, Alex D.D. 1999. "Calculus and Analysis in Early 19th Century Britain: The Work of William Wallace." *Historia Mathematica* **26**: 239–267.

Craik, Alex D.D. 2000. "James Ivory, Mathematician: 'The Most Unlucky Person that Ever Existed.'" *Notes & Records Roy. Soc. London* **54**: 223–247.

Craik, Alex D.D. 2004. "The Origins of Water Wave Theory." *Ann. Rev. Fluid Mech.* **36**: 1–28.

Craik, Alex D.D. 2005. "George Gabriel Stokes on Water Wave Theory." *Ann. Rev. Fluid Mech.* **37**: 23–42.

Craik, Alex D.D. 2007. "Science and Technology in 19th Century Japan: The Scottish Connection." *Fluid Dyn. Res.* **39**: 24–48.

Craik, Alex D.D. & Edwards, Gloria 2004. "In Search of Thomas Knight." *Bull. Brit. Soc. Hist. Math.* **2**: 17–27.

Crilly, Tony 1986. "The Rise of Cayley's Invariant Theory (1841–1862)." *Historia Mathematica* **13**: 241–254.

Crilly, Tony 1988. "The Decline of Cayley's Invariant Theory (1863–1895)." *Historia Mathematica* **15**: 332–347.

Crilly, Tony 1999. "Arthur Cayley as Sadlerian Professor: A Glimpse of Mathematics Teaching at 19th-Century Cambridge." *Historia Mathematica* **26**: 125–160.

Crilly, Tony 2004a. "The *Cambridge Mathematical Journal* and Its Descendants: The Linchpin of a Research Community in the Early and Mid-Victorian Age." *Historia Mathematica* **31**: 455–497.

Crilly, Tony 2004b. "Murphy, Robert". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Crilly, Tony 2004c. "Cayley, Arthur". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Crilly, Tony 2004d. "Sir Thomas Muir". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Crilly, Tony 2006. *Arthur Cayley: Mathematician Laureate of the Victorian Age.* Baltimore: Johns Hopkins Univ. Press.

Cross, J.J. 1985. "Integral Theorems in Cambridge Mathematical Physics 1830–55." In Harman (1985) Ch.5, pp.112–148.

Crowe, Michael J. 1985. *A History of Vector Analysis*. 2nd edn. New York: Dover.

Cunningham, Frank 1990. *James David Forbes, Pioneer Scottish Glaciologist*. Edinburgh: Scottish Academic Press.

Dalrymple, William 2003. *White Mughals: Love and Betrayal in Eighteenth-Century India*. London: Flamingo (HarperCollins).

Dalrymple, William 2004. "Personal Encounters: Europeans in South Asia." In *Encounters: The Meeting of Asia and Europe 1500–1800*, eds. Anna Jackson

& Amin Jaffer, Ch.12, pp.156–169. London: V&A Publications, Victoria & Albert Museum.
Darrigol, Olivier 2000. *Electrodynamics from Ampère to Einstein*. Oxford: Oxford Univ. Press.
Darrigol, Olivier 2002. "Between Hydrodynamics and Elasticity Theory: The First Five Births of the Navier-Stokes Equation." *Arch. Hist. Exact Sci.* **56**: 95–150.
Darrigol, Olivier 2003. "The Spirited Horse, the Engineer, and the Mathematician: Water Waves in Nineteenth-Century Hydrodynamics." *Arch. Hist. Exact Sci.* **58**: 21–95.
Darrigol, Olivier 2005. *Worlds of Flow: A History of Hydrodynamics from the Bernoullis to Prandtl*. Oxford: Oxford Univ. Press.
Darwin, Charles 1859. *On the Origin of Species by Means of Natural Selection*. London: Murray.
Dauglish, Milverton G. & Stephenson, Pleydell K. 1911. *The Harrow School Register 1800–1911*, 3rd edn. London: Longman Green.
Davie, George E. 1961. *The Democratic Intellect*. Edinburgh: Edinburgh Univ. Press.
Davies, George C.B. 1963. *Men for the Ministry. The History of the London College of Divinity*. London: Hodder & Stoughton.
Desmond, Ray 2004. "Clarke, Charles Baron". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.
Domb, Cyril 1908. "James Clerk Maxwell in London 1860–1865." *Notes & Records Roy. Soc. London* **35**: 67–103.
Dubbey, John M. 1978. *The Mathematical Work of Charles Babbage*. Cambridge: Cambridge Univ. Press.
Edwards, Charles H. 1979. *The Historical Development of the Calculus*. New York: Springer.
Ellis, Ieuan 1980. *Seven Against Christ: A Study of "Essays And Reviews"*. Leiden: Brill.
Ellis, Robert Leslie 1865. "Biographical Memoir of Duncan Farquharson Gregory." In Walton (ed.) (1865).
Ellis, Robert Leslie 1863. *The Mathematical and Other Writings of Robert Leslie Ellis M.A.* See Walton (ed.) (1863).
Emmerson, George S. 1977. *John Scott Russell: A Great Victorian Engineer and Naval Architect*. London: Murray.
Enros, Philip C. 1983. "The Analytical Society (1812–1813): Precursor of the Renewal of Cambridge Mathematics." *Historia Mathematica* **10**: 24–47.
Everett, William 1866. *On the Cam: Lectures on the University of Cambridge in England*. Cambridge: S.O. Beeton.

Falconer, Isobel 2004. "Charles Augustin Coulomb and His Fundamental Law of Electrostatics." *Metrologia* **41**: S107–114. Institute of Physics.
Fauvel, John, Flood, Raymond & Wilson, Robin (eds.) 2000. *Oxford Figures: 800 Years of the Mathematical Sciences*. Oxford: Oxford Univ. Press.
Ferrers Norman M. (ed.) 1871. *Mathematical Papers of the Late George Green*. London: Macmillan.
Ferrers, Norman M. 1892. "Memoir of Harvey Goodwin." *The Caian* (Lent term 1892).
Feuchtwanger, E.J. 2004. "Gorst, John Eldon". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.
Fisch, Menachem & Schaffer, Simon (eds.) 1991. *William Whewell, a Composite Portrait*. Oxford: Clarendon.
Forbes, James D. 1838. In *Testimonials in Favour of The Rev. Philip Kelland, M.A. . . . as Candidate for the Chair of Mathematics in the University of Edinburgh*. Printed pamphlet 16pp. [Copy in Edinburgh University Library.]
Forbes, James D. 1845. "Reply to Mr Hopkins on the Motion of Glaciers." *Philos. Mag.* **26**: 404–418.
Forrest, Barbara & Gross, Paul R. 2004. *Creationism's Trojan Horse*. Oxford: Oxford Univ. Press.
Forsyth, Arthur R. 1935. "Old Tripos Days at Cambridge." *Math. Gazette* **19**: 162–179.
Fowler, Joseph T. 1904. *Durham University: Earlier Foundations and Present Colleges*. College History series. London: F.E. Robinson.
Fox, Robert 2004a. "Clifton, Robert Bellamy". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.
Fox, Robert 2004b. "Dawson, John". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.
Garland, Martha M. 1980. *Cambridge Before Darwin. The Ideal of a Liberal Education, 1800–1860*. Cambridge: Cambridge Univ. Press.
Gascoigne, John 1984. "Mathematics and Meritocracy: The Emergence of the Cambridge Mathematical Tripos." *Social Studies of Science* **14**: 547–84.
Gillispie, Charles C. 1951. *Genesis and Geology*. Cambridge, Mass.: Harvard Univ. Press.
Glaisher, James W.L. 1896. Biographical Article of John Couch Adams. In Adams (W.G.) (1896).
Goldman, Lawrence 2004. "Fawcett, Henry". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.
Goodwin, Harvey 1845. *Considerations Respecting the Exercises in the Schools and Other Matters Connected with the Qualification for the Degree of*

B.A. 35pp. pamphlet. Cambridge: Deighton and Stevenson; London: Rivington.

Goodwin, Harvey 1846. *An Elementary Course of Mathematics Designed Principally for Students of the University of Cambridge*. Cambridge: J. & J.J. Deighton (6th edn. revised and enlarged by P. T. Main, 1866).

Goodwin, Harvey 1847. *A Collection of Problems and Examples, Adapted to the "Elementary Course of Mathematics" by Harvey Goodwin*. Cambridge: J. & J.J. Deighton (2nd edn. 1851).

Goodwin, Harvey 1851. *A Defence of Certain Portions of an 'Elementary Course of Mathematics' in Reply to the Remarks on the Same, in Dr. Whewell's Recent Work on 'Cambridge Education'*. Cambridge.

Goodwin, Harvey 1855. *How Christ's Promises Are Fulfilled. A Farewell Sermon [on Matt. xix. 27, 28, 29] Preached in Trinity Church, Birkenhead . . . on the Occasion of the Departure of the Bishop of Natal and Other Members of the Natal Mission*. Cambridge & Liverpool.

Goodwin, (Bishop) Harvey 1864. *Memoir of Bishop Mackenzie*. Cambridge: Deighton, Bell; London: Bell & Daldy.

Goodwin, (Bishop) Harvey 1889. *The Foundations of the Creed*. London: John Murray.

Goodwin, (Bishop) Harvey & Vyvyan, Thomas G. 1867. *Elementary Analytical Geometry*. Cambridge.

Gopal, Sarvepalli 1965. *British Policy in India 1858–1905*. Cambridge: Cambridge Univ. Press.

Gowda, Made 1997. *Modern Mysore State 1881–1902, a Study of the Elite, Polity and Society*. Mysore: University of Mysore.

Grabiner, Judith V. 2004. "Newton, Maclaurin and the Authority of Mathematics." *Amer. Math. Mon.* **111**: 841–852.

Grattan-Guinness, Ivor 1985. "Mathematics and Mathematical Physics from Cambridge, 1815–40: A Survey of the Achievements and of the French Influences." In Harman (1985), pp.84–111.

Grattan-Guinness, Ivor (ed.) 1994. *Companion Encyclopedia of the History and Philosophy of the Mathematical Sciences*. 2 vols. London & New York: Routledge.

Grattan-Guinness, Ivor 2001. "The Contributions of J. J. Sylvester, F.R.S., to Mechanics and Mathematical Physics." *Notes & Records Roy. Soc. London* **55**(2): 253–265.

Gray, Robert 1876. *Life of Robert Gray, Bishop of Capetown and Metropolitan of Africa* edited by his son, the Rev. Charles Gray. 2 vols. London, Oxford & Cambridge: Rivingtons.

Green, George 1828. *Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism*. Nottingham: privately printed.

Green, George 1833. “Mathematical Investigations Concerning the Laws of the Equilibrium of Fluids Analogous to the Electrical Fluid, with Other Similar Researches.” *Trans. Cambridge Philos. Soc.* **5**(1): 1–64. [Also in Ferrers (1871).]

Green, George 1835. “On the Determination of the Exterior and Interior Attractions of Ellipsoids of Variable Densities.” *Trans. Cambridge Philos. Soc.* **5**(3): 395–430. [Also in Ferrers (1871).]

Green, George 1836. “Researches on the Vibration of Pendulums in Fluid Media.” *Trans. Roy. Soc. Edinburgh* **13**(1): 54–62. [Also in Ferrers (1871).]

Green, George 1838. On the Laws of Reflexion and Refraction of Light at the Common Surface of Two Non-Crystallized Media. *Trans. Cambridge Philos. Soc.* **7**: 1–24, 113–120. [Also in Ferrers (1871).]

Gregory, Duncan F. 1841. *Examples of the Processes of the Differential and Integral Calculus* [2nd edn. 1846]. Cambridge: J. & J.J. Deighton etc.

Gregory, Duncan F. & Walton, William 1845. *A Treatise on the Application of Analysis to Solid Geometry*. Cambridge: J. & J.J. Deighton.

Gregory, Duncan F. 1865. *The Mathematical Writings of Duncan Farquharson Gregory M.A.* See Walton (ed.) 1865.

Grove’s Dictionary of Music and Musicians 1906. 5 vols. ed. J.A. Fuller Maitland. London: Macmillan & Co.

Guicciardini, Nicolo 1989. *The Development of Newtonian Calculus in Britain 1700–1800*. Cambridge: Cambridge Univ. Press.

Gunning, Henry 1854. *Reminiscences of the University, Town, and County of Cambridge from the Year 1780*. 2 vols. London: Bell; Cambridge: Charles Wootton.

Hall, Maria Boas 1984. *All Scientists Now: The Royal Society in the Nineteenth Century*. Cambridge: Cambridge Univ. Press.

Hall, A. Rupert 1969. *The Cambridge Philosophical Society: A History 1819–1969*. Cambridge: Cambridge Philosophical Society.

Hamilton, William 1836. “Study of Mathematics: University of Cambridge.” *Edinburgh Review* **62**(126): 409–455.

Hamilton, William R. 1846. “On Symbolic Geometry.” *Cambridge and Dublin Math. J.* **1**: 45–57, 137–154, 256–263.

Harman, Peter M. (ed.) 1985. *Wranglers and Physicists; Studies on Cambridge Physics in the Nineteenth century*. Manchester: Manchester Univ. Press.

Harman, Peter M. 1990–2002. *The Scientific Letters and Papers of James Clerk Maxwell*. 3 vols. Cambridge: Cambridge Univ. Press.

Harman, Peter M. 1998. *The Natural Philosophy of James Clerk Maxwell*. Cambridge: Cambridge Univ. Press.

Harris, Tina 2003. In *Asymptopia*, Centre for Mathematical Sciences Newsletter (Oct. 2003), University of Cambridge.

Hayavadana Rao, Conjeeveram (ed.) 1929. *Mysore Gazetteer, vol.4 Administrative*. Bangalore: Government Press.

Hayes, James W. 1887. *The Maharajah's Tour: Being a Narrative of the Royal Progress Made by His Highness Chamrajendra Wadeyar Bahadur, G.C.S.I., Maharajah of Mysore, Through the Western Portion of His Dominions, from November 1885 to January 1886*. Edited and extended by Hayes from articles in the "Bangalore Daily Post". Bangalore [British Library copy missing].

Hearnshaw, Fossey J.C. 1929. *The Centenary History of King's College London 1828–1928*. London: Harrap.

Hettne, Bjørn 1978. *The Political Economy of Indirect Rule: Mysore 1881–1947*. London & Malmö: Scandinavian Institute of Asian Studies Monograph No.32.

Hilken, Thomas J.N. 1967. *Engineering at Cambridge University 1783–1965*. Cambridge: Cambridge Univ. Press.

Hinchliff, Peter 1964. *John William Colenso, Bishop of Natal*. London, Edinburgh etc.: Nelson.

Hopkins, J. Ellice 1872. *Christ the Consoler. A Book of Comfort for the Sick*. With a preface by the . . . Bishop of Carlisle. London: Longmans & Co.

Hopkins, J. Ellice 1879. *A Plea for the Wider Action of the Church of England in the Prevention of the Degradation of Women, as Submitted to a Committee of Convention on July 3, 1879*. London: Hatchards.

Hopkins, William 1833. *Elements of Trigonometry*. London: Society for the Diffusion of Useful Knowledge. [Reprinted in 1847 in volume 2 of the Society's *Library of Useful Knowledge*.]

Hopkins, William 1835. "On Aerial Vibrations in Cylindrical Tubes." *Trans. Camb. Philos. Soc.* **5**: 231–270.

Hopkins, William 1836a. "Researches in Physical Geology." *Trans. Camb. Philos. Soc.* **6**: 1–84.

Hopkins, William 1836b. *An Abstract of a Memoir on Physical Geology, with a Further Exposition of Certain Points Connected with the Subject*, 48pp. Cambridge: Pitt Press [Copy in Wren Library, Trinity College].

Hopkins, William 1839. "On the Phenomena of Precession and Nutation, Assuming the Fluidity of the Interior of the Earth." *Philos. Trans. Roy. Soc. London* (1839), 381–424.

Hopkins, William 1840. "On Precession and Nutation, Assuming the Interior of the Earth to be Fluid and Heterogeneous." *Philos. Trans. Roy. Soc. London* (1840), 193–208.

Hopkins, William 1841. *Remarks on Certain Proposed Regulations Respecting the Studies of the University and the Period of Conferring the Degree of B.A.* Cambridge: J.J. Deighton.

Hopkins, William 1842. "On the Thickness and Constitution of the Earth's Crust." *Philos. Trans. Roy. Soc. London* (1842), 43–56.

Hopkins, William 1845. "Remarks on Professor Forbes's Reply to His Letters on Glaciers." *Philos. Mag.* **26**: 593–599.

Hopkins, William 1852. *Address Delivered at the Anniversary Meeting of the Geological Society of London, on 20th February, 1852*. London: Richard Taylor.

Hopkins, William 1853. Presidential Address. *Rept. Brit. Assoc. Adv. Sci. for 1853*. [also separately, as *Address Delivered to the Hull Meeting of the British Association for the Advancement of Science, September 7, 1853*, 20pp., London: Taylor & Francis].

Hopkins, William 1854. *Remarks on the Mathematical Teaching of the University of Cambridge*. Cambridge: privately printed, n.d. (Copy in Trinity College Library).

Hopkins, William 1857. "Geology." In *Cambridge Essays Contributed by Members of the University*, pp.172–240. London: J.W. Parker & Son.

Howarth, Osbert J.R. 1931. *The British Association for the Advancement of Science: A Retrospect 1831–1931*. London: The British Association.

Howson, Geoffrey 1982. *A History of Mathematics Education in England*. Cambridge: Cambridge Univ. Press.

Huber, Victor A. 1843. *The English Universities*, 2 vols, abridged trans. of orig. German edn. by Francis W. Newman. London: Wm. Pickering; Manchester: Simms & Dinham.

Hughes, Thomas C. (rev. Katherine Prior) 2004. "Phear, John Budd". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Hunt, Bruce J. 1991. *The Maxwellians*. Ithaca and London: Cornell Univ. Press.

Hutchins, Roger 2004. "Adams, John Couch". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Huxley, Leonard 1918. *Life and Letters of Sir Joseph Dalton Hooker*. 2 vols. London: Murray.

Huxley, Thomas H. 1908. *Discourses; Biological and Geological*. London: Macmillan.

Jeal, Tim 2001. *Livingstone*. Yale, U.S.A.: Nota Bene [1st edn. 1973, Heinemann].

Jones, Harold Spencer 1947. *John Couch Adams and the Discovery of Neptune*, 43pp. Cambridge: Cambridge Univ. Press.

Kargon, Robert H. 1977. *Science in Victorian Manchester*. Baltimore & London: The Johns Hopkins Univ. Press.

Knight, David 2004. "Garnett, William". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Knight, William A. 1903. *Some Nineteenth-Century Scotsmen*. Edinburgh and London: Oliphant, Anderson & Ferrier.

Knott, Cargill G. 1911. *Life and Scientific Work of Peter Guthrie Tait*. Cambridge: Cambridge Univ. Press.

Kollerstrom, Nicholas 2006. "An Hiatus in History: The British Claim for Neptune's Co-Prediction, 1845–1846: Part 1." *History of Science* **44**: 1–28; ". . . Part 2." *ibid.* 349–371.

Lacroix, Silvestre F. 1802. *Traité Élémentaire du Calcul Différentiel et du Calcul Intégral*. Paris: Duprat.

Lacroix, Silvestre F. 1816. *An Elementary Treatise of the Differential and Integral Calculus* trans. by Charles Babbage, John Herschel & George Peacock. Cambridge: J. Deighton.

Lamb, Horace 1895. *Hydrodynamics* (also 4th edn. 1916, 6th edn. 1932). Cambridge: Cambridge Univ. Press.

Lardner, Dionysius 1829–39. *Dr Lardner's Cabinet Cyclopaedia*. London: Longman, Rees, Orme, Brown & Green, and J. Taylor.

Larmor, Joseph (ed.) 1907. *Memoir and Scientific Correspondence of the Late Sir George Gabriel Stokes. . . .* 2 vols. Cambridge: Cambridge Univ. Press. [Selected correspondence only, excluding that with William Thomson, Lord Kelvin.]

[Lewis, John Delaware] "John Smith (of Smith Hall) Gent." 1849. *Sketches of Cantab* [2nd edn. 1850]. London: G. Earle.

Lubenow, William C. 1998. *The Cambridge Apostles, 1820–1914: Liberalism, Imagination, and Friendship in British Intellectual and Professional Life*. Cambridge: Cambridge Univ. Press.

Lützen, Jesper 1984. "Joseph Liouville's Work on the Figures of Equilibrium of a Rotating Mass of Fluid." *Arch. Hist. Exact Sci.* **30**: 113–166.

Lyell, (Sir) Charles 1845. *Travels in North America: With Geological Observations on the United States, Canada and Nova Scotia*. London: J. Murray.

Lyell, (Sir) Charles 1881. *Life, Letters and Journals of Sir Charles Lyell, Bart. Edited by His Sister-in-Law, Mrs. Lyell.* 2 vols. London: John Murray.

Lynch, John M. (ed.) 2002. *Creationism and Scriptural Geology, 1817–1857*. 7 vols. London: Thoemmes.

McConnell, Anita 2004. "Pratt, John Henry". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Macfarlane, Alexander 1916. *Lectures on Ten British Mathematicians of the Nineteenth Century*. New York: Wiley.

McKitterick, David 2001. "Where Did Undergraduates Get Their Books?" In Smith & Stray (2001), pp.165–176.

McMahon, M.K.C. 2004. "Ellis, Alexander John". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Madras Almanac 1830–35. Madras: Asylum Press.

Marsden, Ben 2004. "Willis, Robert". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Mason, Hilary 2004. "J.E.A. Steggall: Teaching Mathematics 1880–1933." *Bull. Brit. Soc. Hist. Math.* **1**: 27–38.

Matthew, H. Colin G. 2004. "Courtney, Leonard Henry, Baron Courtney of Penwith". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Maxwell, James Clerk 1873. *A Treatise on Electricity and Magnetism*. 2 vols. Oxford: Clarendon Press (2nd edn. 1881).

Maxwell, James Clerk 1890. *The Scientific Papers of James Clerk Maxwell*, edited by W.D. Niven. 2 vols. Cambridge: Cambridge Univ. Press.

Morrell, Jack 1997. *Science, Culture and Politics in Britain, 1750–1870*. Aldershot UK: Variorum collected studies series CS567.

Moyal, Ann 1986. *'A Bright and Savage Land': Scientists in Colonial Australia*. Sydney: Collins.

Muir, Thomas 1884. *The Promotion of Research; with Special Reference to the Present State of the Scottish Universities and Secondary Schools*. Paisley: Privately printed by Gardiner. [Sometimes bound with *Proc. Edin. Math. Soc.* **2** (1884).]

Mullinger, James Bass (rev. Adrian Rice) 2004. "Todhunter, Isaac". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Murphy, Robert 1833. *Elementary Principles of the Theories of Electricity, Heat and Molecular Actions. Pt. 1. On Electricity*. Cambridge: J. and J.J. Deighton.

Murphy, Robert 1835. "Second Memoir on the Inverse Method of Indefinite Integrals." *Trans. Cambridge Philos. Soc.* **5**: 113–148.

Murphy, Robert 1839. *A Treatise on the Theory of Algebraical Equations*. London: Library of Useful Knowledge: Mathematics, vol. 1.

Newman, (Cardinal) John Henry 1959. *The Idea of a University* [First publ. 1852]. Reprint, New York: Image Books.

O'Brien, Matthew 1842. "On the Propagation of Luminous Waves in the Interior of Transparent Bodies." *Trans. Camb. Phil. Soc.* **7**: 397–438.

O'Donoghue, F. & Hake, Henry M. 1925. *Catalogue of Engraved British Portraits Preserved in the Department of Prints and Drawings in the British Museum*. 6 vols.

Olson, Richard 1975. *Scottish Philosophy and British Physics 1750–1880. A Study in the Foundations of the Victorian Scientific Style*. Princeton, New Jersey: Princeton Univ. Press.

Panteki, Maria 1987. "William Wallace and the Introduction of Continental Calculus to Britain: A Letter to George Peacock." *Historia Mathematica* **14**: 119–132.

Panteki, Maria 2003. "French 'Logique' and British 'Logic': On the Origins of Augustus De Morgan's Early Logical Enquiries, 1805–1835." *Historia Mathematica* **30**: 278–340.

Paris, Richard 1996. "The Mathematical Work of G.G. Stokes." *Math. Today* **32** (3–4): 43–46. Southend-on-Sea, UK: IMA.

Parshall, Karen H. & Rowe, David E. 1994. *The Emergence of the American Mathematical Research Community 1876–1900: J.J. Sylvester, Felix Klein, and E.H. Moore*. (Corrected reprint 1997.) History of Mathematics series vol. 8, American Mathematical Soc. & London Mathematical Soc.

Parshall, Karen H. 1998. *James Joseph Sylvester: Life and Work in Letters*. Oxford: Clarendon.

Parshall, Karen H. 2006. *James Joseph Sylvester: Jewish Mathematician in a Victorian World*. Baltimore: Johns Hopkins Univ. Press.

Pattenden, Philip 2002. "The Noblest Prospect: Scotland in Peterhouse." *Peterhouse Annual Record, 2001/2002*, pp.97–106. Peterhouse, Cambridge.

Peacock, George 1820. *A Collection of Examples of the Application of the Differential and Integral Calculus*. Cambridge: Smith, Deighton.

Peacock, George 1841. *Observations on the Statutes of the University of Cambridge*. London: J.W. Parker; Cambridge: J. & J.J. Deighton.

Pearce, Ernest H. (rev. D. Hilliard) 2004. "Barry, Alfred". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Pearson, Karl 1914–30. *The Life, Letters, and Labours of Francis Galton*. 3 vols. Cambridge: Cambridge Univ. Press.

Pearson, Karl 1936. "Old Tripos Days at Cambridge, as Seen from Another Viewpoint." *Math. Gazette* **20**: 27–36.

Phillips, Christopher 2006. "Robert Woodhouse and the Evolution of Cambridge Mathematics." *History of Science* **44**: 69–93.

Playfair, John 1808; 1822. "Review of Laplace, *Traité de Méchanique Céleste*." *Edinburgh Rev.* **11**(22): 249–284. [Also in *The Works of John Playfair, Esq.* 1822, 4 vols., **4**: 259–330. Edinburgh: Constable.]

Powell, Baden 1832. *The Present State and Future Prospects of Mathematical and Physical Studies in the University of Oxford, Considered in a Public Lecture*, etc., 45pp. Oxford: J.H. Parker; London: J.G. & F. Rivington.

Pratt, John Henry 1836. *Mathematical Principles of Mechanical Philosophy and Their Application to the Theory of Universal Gravitation* [later edns. 1842, 1845]. Cambridge: J. & J.J. Deighton.

Pratt, John Henry 1849. *Notes Written During the Bishop of Calcutta's Second Metropolitan Visitation*, 36pp. pamphlet, reprinted from the 'Calcutta Intelligencer', February 1849. Calcutta [Copy in British Library].

Pratt, John Henry 1856. *Scripture and Science Not at Variance, or, the Historical Character and Plenary Inspiration of the Earlier Chapters of Genesis Unaf-*

fected by the Discoveries of Science [seven editions with variations in title publ. between 1856 and 1872]. London: Hatchards.

Pratt, John Henry 1860. *A Treatise on Attractions, Laplace's Functions, and the Figure of the Earth*. Cambridge: Macmillan.

Pratt, John Henry 1865. *Some Account of Endowments & Institutions in Connexion with the Diocese and Archdeaconry of Calcutta*. Calcutta: R.C. Lepage & Co.

Pratt, John Henry 1871. *The Descent of Man, in Connection with the Hypothesis of Development*, 32pp. London: Hatchards.

Rankin, Robert A. 1983. "The First Hundred Years (1883–1983)" [centenary of the Edinburgh Math. Soc.]. *Proc. Edin. Math. Soc.* **26**: 135–150.

Rawnsley, (Canon) Hardwicke D. 1896. *Harvey Goodwin, Bishop of Carlisle, a Biographical Memoir*. London: John Murray.

Rayleigh, Lord (J.W. Strutt) 1903. "Obituary of Sir George Gabriel Stokes." In Stokes (1880–1905), vol. 5. [Also in *Proc. Roy. Soc. London* (1903).]

Rept.: See *Commissioners' Report* 1852.

Rice, Adrian 1997. "Inspiration or Desperation? Augustus De Morgan's Appointment to the Chair of Mathematics at London University in 1828." *British J. Hist. Sci.* **30**: 257–274.

Rice, Adrian 1999. "What Makes a Great Mathematics Teacher? The Case of Augustus De Morgan." *Amer. Math. Monthly* **106**(6): 534–552.

Rice, B. Lewis 1897. *Mysore: A Gazetteer Compiled for Government*. 2 vols. Westminster: Constable.

Robinson, Francis (ed.) 1989. *The Cambridge Encyclopaedia of India, Pakistan, Bangladesh. . . .* Cambridge: Cambridge Univ. Press.

Rothblatt, Sheldon 1968. *The Revolution of the Dons*. London: Faber & Faber.

Rouse Ball, Walter W. 1888. *A Short Account of the History of Mathematics*. London: Macmillan & Co.

Rouse Ball, Walter W. 1889. *A History of the Study of Mathematics at Cambridge*. Cambridge: Cambridge Univ. Press.

Rouse Ball, Walter W. 1911–12. "The Cambridge School of Mathematics." *Math. Gazette* **6**: 311–323.

Rouse Ball, Walter W. 1918. *Cambridge Papers*. London: Macmillan.

Rouse Ball, Walter W. & Venn, John A. (eds.) 1911. *Admissions to Trinity College, Cambridge, Vol. IV, 1801 to 1851*. London: Macmillan.

Routh, Edward J. & Watson, Henry W. 1860. *Cambridge Senate-House Problems and Riders*. Cambridge: Macmillan and Co.

Royal Society Catalogue of Scientific Papers 1800–1900. 19 vols. 1867–1925. London: Eyre & Spottiswoode for H.M.S.O.

Russell, J. Scott & Robison, (Sir) John 1837. "Report on Waves." *Rep. Br. Assoc. Adv. Sci. 1837*, pp.417–496.

Russell, J. Scott 1844. "Report on Waves." *Rep. Br. Assoc. Adv. Sci. 1844*, pp.311–390.

Searby, Peter 1997. *A History of the University of Cambridge, Vol. II, 1750–1870*. Cambridge: Cambridge Univ. Press.

Seccombe, Thomas (rev. Philip S. Bagwell) 2004. "Laing, Samuel". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Sedgwick, Adam 1836. *Four Letters to the Editor of the "Leeds Mercury"* (first published 1834 and here reprinted as a pamphlet). Cambridge: Pitt Press, J. Smith.

Shama Rao M. 1936. *Modern Mysore, from the Coronation of Chamaraja Wodeyer X in 1868 to the Present Time*. Bangalore: Higginbothams.

Shanks, Niall 2004. *God, the Devil, and Darwin*. Oxford: Oxford Univ. Press.

Smart, Robert N. 2004. *Biographical Register of the University of St Andrews 1747–1897*. St Andrews, Scotland: University of St Andrews Library Publications.

Smith, Crosbie 1985. "Geologists and Mathematicians: The Rise of Physical Geology." In Harman (1985), pp.49–83.

Smith, Crosbie 1989. "William Hopkins and the Shaping of Dynamical Geology, 1830–1860." *Brit. J. Hist. Sci.* **22**: 27–52.

Smith, Crosbie 2004. "Hopkins, William". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Smith, Crosbie & Wise, M. Norton 1989. *Energy and Empire. A Biographical Study of Lord Kelvin*. Cambridge: Cambridge Univ. Press.

Smith, John J. (ed.) 1840. *The Cambridge Portfolio*. Cambridge: Parker, Deighton.

Smith, Jonathan 2001. "Trinity College Annual Examinations in the Nineteenth Century." In Smith & Stray (2001), pp.122–138.

Smith, Jonathan & Stray, Christopher (eds.) 2001. *Teaching and Learning in 19th-Century Cambridge*. Cambridge: The Boydell Press & Cambridge University Library.

Smith, Jonathan & Stray, Christopher (eds.) 2003. *Cambridge in the 1830s: The Letters of Alexander Chisholm Gooden 1831–1841*. Cambridge: Boydell Press and Cambridge Univ. Press.

Smith, Vincent A. 1923. *The Oxford History of India from the Earliest Times to the End of 1911*. 2nd edn. Oxford: Clarendon.

Smyth, Warington W. 1867. "William Hopkins, M.A., LL.D., F.R.S." (obituary). *Quart. J. Geol. Soc. Lond.* **23**: xxix–xxxii.

Standage, Tom 2000. *The Neptune File. Planet Detectives and the Discovery of Worlds Unseen*. London: Allen Lane and Penguin.

Steegman, John 1954. *Cambridge*. London: Batsford.

[Stephen, Leslie] "A Don" 1865. *Sketches from Cambridge*. London & Cambridge: Macmillan.
Stephen, Leslie 1885. *Life of Henry Fawcett*. London: Smith, Elder.
Stephen, Leslie 1977. *Sir Leslie Stephen's Mausoleum Book*, ed. and intro. by Alan Bell. Oxford: Clarendon.
Stewart, Hugh 2002. "The Last Wooden Spoon" in *Asymptopia* (*Cambridge University Centre for Mathematical Sciences Newsletter*, March 2002), Cambridge.
Stigler, Stephen M. 1986. *The History of Statistics: The Measurement of Uncertainty Before 1900*. Cambridge, Mass.: Harvard Univ. Press.
Stokes, George G. 1845. "On the Theories of the Internal Friction of Fluids in Motion, and of the Equilibrium and Motion of Elastic Solids." *Trans. Camb. Philos. Soc.* **8**: 287–319.
Stokes, George G. 1847. "On the Theory of Oscillatory Waves." *Trans. Camb. Philos. Soc.* **8**: 441–455. Also in Stokes (1880–1905, **1**), with additional Appendices and Supplement.
Stokes, George Gabriel 1869. Presidential Address. *Rept. Br. Assoc. Adv. Sci. 1869*, pp.civ–cv.
Stokes, George Gabriel 1880–1905. *Mathematical & Physical Papers of Sir George Gabriel Stokes*. 5 vols. Cambridge: Cambridge Univ. Press.
Stokes, George Gabriel 1891a; 1893. *Natural Theology: The Gifford Lectures*. 2 vols. London & Edinburgh: A. & C. Black.
Stokes, George Gabriel 1891b. "Genesis and Science." *The Expositor* 4th series, **3**: 46ff.
Stokes, George Gabriel 1897. *Conditional Immortality: A Help to Sceptics*. London: James Nisbet.
Stokes, Henry P. 1911. *The Esquire Bedells of the University of Cambridge from the 13th Century to the 20th Century*. Cambridge: Deighton, Bell, etc. for the Cambridge Antiquarian Soc.
Sviedrys, Romualdas 1976. "The Rise of Physics Laboratories in Britain." *Hist. Stud. Phys. Sci.* **7**: 405–436.
Swade, Doron 2000. *The Cogwheel Brain: Charles Babbage and the Quest to Build the First Computer*. London: Little, Brown & Co.
Tait, Peter Guthrie & Steele, William J. 1856. *A Treatise on the Dynamics of a Particle*. Cambridge: Macmillan.
Tait, Peter Guthrie 1898; 1900. *Scientific Papers*. 2 vols. Cambridge: Cambridge Univ. Press.
Tanner, Joseph R. 1917. *The Historical Register of the University of Cambridge*. Cambridge: Cambridge Univ. Press.
Temple, Frederick *et al.* 1860. (Frederick Temple, Rowland Williams, Baden Powell, Henry Bristow Wilson, Charles W. Goodwin, Mark

Pattison and Benjamin Jowett). *Essays and Reviews*. London: J.W. Parker & Son.

Thompson, Silvanus P. 1910. *The Life of William Thomson Baron Kelvin of Largs*. 2 vols. London: Macmillan.

Thomson, William (Lord Kelvin) 1899. "On the Age of the Earth as an Abode Fitted for Life." *Phil. Mag.* **47**: 66–90.

Thomson, William (Lord Kelvin) & Tait, Peter G. 1867; 1879. *Treatise on Natural Philosophy*. 2 vols. 2nd edn. with additions, 1879 etc. Cambridge: Cambridge Univ. Press.

Thomson, William (Lord Kelvin) & Tait, Peter G. 1872. *Elements of Natural Philosophy*. Cambridge: Cambridge Univ. Press.

Toplis, John 1805. "On the Decline of Mathematical Studies, and the Sciences Dependent upon Them." *Philos. Mag.* **20**: 25–31.

Toplis, John (trans.) 1814. *A Treatise upon Analytical Mechanics; Being the First Book of the Mécanique Céleste of M. le Comte Laplace*, with notes. Nottingham: Barnett.

Truesdell, Clifford 1979. *The Tragicomical History of Thermodynamics, 1822–1854*. New York: Springer.

Turnbull, Herbert Westren, rev. A.J. [Tony] Crilly 2004. "MacMahon, Percy Alexander". In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Underwood, Malcolm 2001. "The Revolution in College Teaching: St John's College, 1850–1926." In Smith & Stray (2001), pp.107–121.

Vadivelu, A. ("Journalist") 1900. *Some Mysore Worthies*. Madras: Thompson & Co. [Reprint, Cambridge: Chadwyck-Healey, 1996.]

Venn, John 1898. *Biographical History of Gonville and Caius College, 1349–1897*. 6 vols. Cambridge: Cambridge Univ. Press.

Venn, John 1913. "College Life and Ways Sixty Years Ago." Appendix to *Early Collegiate Life*, pp.253–282. Cambridge: W. Heffer & Sons.

Venn, John & Venn, John A. 1940. *Alumni Cantabrigiensis: A Biographical List of All Known Students, Graduates and Holders of Office at the University of Cambridge from the Earliest Times to 1900. Part 2: From 1752 to 1900* [ed. J.A. Venn]. Cambridge: Cambridge Univ. Press.

Victoria Institute J. 1866–. *Journal of the Transactions of the Victoria Institute or Philosophical Society of Great Britain*, annual.

Walsh, Benjamin Dann 1837. *A Historical Account of the University of Cambridge, and Its Colleges; in a Letter to the Earl of Radnor*, 162pp. pamphlet. 2nd edn. London: J. Ridgway & Sons.

Walton, William (ed.) 1863. *The Mathematical and Other Writings of Robert Leslie Ellis*, with a biographical memoir by H. Goodwin. Cambridge: Deighton, Bell.

Walton, William (ed.) 1865. *The Mathematical Writings of Duncan Farquharson Gregory M.A.*, with a biographical memoir by Robert Leslie Ellis. Cambridge and London: Deighton, Bell.

Warington, George 1867. "On the Credibility of Darwinism." *J. Trans. Victoria Inst. (Philos. Soc. of Great Britain) for 1867–68*, pp.39–62.

Warwick, Andrew 2001. "The Analytical Revolution from Below: Private Teaching and Mathematical Reform in Georgian Cambridge." In Smith & Stray (2001), pp.5–30.

Warwick, Andrew 2003. *Masters of Theory: Cambridge and the Rise of Mathematical Physics*. Chicago and London: Univ. of Chicago Press.

Watson, Henry W. 1876. *A Treatise on the Kinetic Theory of Gases*. Oxford: Clarendon.

Watson, Henry W. & Burbury, Samuel H. 1885; 1889. *The Mathematical Theory of Electricity and Magnetism*. 2 vols. Oxford: Clarendon.

Whewell, William 1836. *Thoughts on the Study of Mathematics as a Part of a Liberal Education*. 2nd edn. Cambridge: Deighton; London: J.W. Parker.

Whewell, William 1837. *History of the Inductive Sciences, from Earliest to the Present Times*. 3 vols. Cambridge: Deighton.

Whewell, William 1845. *Of a Liberal Education in General; and with Particular Reference to the Leading Studies of the University of Cambridge*. London: J.W. Parker.

Whewell, William 1850; 1852. *Of a Liberal Education in General; and with Particular Reference to the Leading Studies of the University of Cambridge. Part II: Discussions of Changes 1840–1850*; *Part III: The Revised Statutes 1851–1852*. London: J.W. Parker.

Whiting, Charles E. 1932. *The University of Durham 1832–1932*. London: Sheldon Press.

Whittaker, (Sir) Edmund 1951. *A History of the Theories of Aether and Electricity. Vol. 1: The Classical Theories* (2nd enlarged edn.). London: Nelson.

Williams, Perry 1991. "Passing on the Torch: Whewell's Philosophy and the Principles of English University Education." In Fisch & Schaeffer (1991), pp.117–147.

Wilson, David B. 1985. "The Educational Matrix: Physics Education at Early Victorian Cambridge, Edinburgh and Glasgow Universities." In Harman (1985), pp.12–48.

Wilson, David B. 1987. *Kelvin & Stokes, a Comparative Study in Victorian Physics*. Bristol: Adam Hilger.

Wilson, David B. (ed.) 1990. *The Correspondence Between Sir George Gabriel Stokes and Sir William Thomson Baron Kelvin of Largs*. 2 vols. Cambridge: Cambridge Univ. Press.

Winstanley, Denys A. 1940. *Early Victorian Cambridge*. Cambridge: Cambridge Univ. Press.

Winstanley, Denys A. 1947. *Later Victorian Cambridge*. Cambridge: Cambridge Univ. Press.

Wintle, Justin (ed.) *Makers of Nineteenth Century Culture 1800–1914*. London. Boston, etc.: Routledge & Kegan Paul.

Wirgman, A. Theodore 1909. *Life of James Green, Doctor of Divinity, Rector and Dean of Maritzburg, Natal*. London: Longmans, Green.

Woiack, Joanne 2004. “Pearson, Karl”. In *Oxford Dictionary of National Biography*. Oxford: Oxford Univ. Press.

Wood, Alastair 1995. “George Gabriel Stokes 1819–1903, an Irish Mathematical Physicist.” *Irish Math. Soc. Bull.* **35**: 49–58.

Wood, Alastair 2003. “Sir G.G. Stokes—A Hundred Years On.” *Math. Today* **39**(1): 15–19. Southend-on-Sea, UK: IMA.

Wood, Christopher 1971. *Dictionary of Victorian Painters*. Woodbridge, Suffolk: Baron Publishing for the Antique Collectors’ Club.

Woodward, (Sir) Llewellyn 1962. *The Age of Reform 1815–1870* (The Oxford History of England series). 2nd edn. Oxford: Clarendon Press.

Wordsworth, Christopher 1874. *Social Life at the English Universities in the Eighteenth Century*. Cambridge: Deighton, Bell.

Wratislaw, Albert H. 1850. *Observations on the Cambridge System, Partly in Reply to, Partly Suggested by Dr. Whewell’s Recent Educational Publications*. 2nd edn. 34 + 18pp. Cambridge: J. Deighton.

[Wright, John M.F.] 1827. *Alma Mater; or Seven Years at the University of Cambridge, by a Trinity-Man*. 2 vols. London: Black, Young & Young.

Wright, John M.F. 1830–31. *The Private Tutor and Cambridge Mathematical Repository*. Cambridge: W.P. Grant.

Young, Thomas 1821. *Elementary Illustrations of the Celestial Mechanics of Laplace*, Book 1. London: Murray.

Indices

Index of Personal Names

Names of post-1950 authors cited in the text and references are omitted from this Index. Numbers in *Italic* type indicate text illustrations; those in **bold** type are colour plates; the letter "n" following a page number denotes a footnote.

General Index

This index excludes personal names. Colleges not identified by place are in Cambridge.