Pure and Practical Women

Mathematics, Science and Gender around 1900, with special reference to Grace Chisholm Young and Hertha Ayrton

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Contents

The decades around 1900 were a significant period in the construction of modern mathematics and science when many long-lasting assumptions about the nature of the disciplines, and their appropriateness for either gender, began to take root. It was also a time when Victorian notions of distinct male and female intellects were being increasingly challenged, not least by the movement for women's higher education and the accelerating campaign for suffrage. Explanations for the virtual absence of women's names from general histories of mathematics are often based on arguments centring on the innately masculine configuration of the discipline which made femininity and mathematics opposing terms. To be a mathematician was to be unwomanly and, conversely, manliness was manifested by success at mathematics. In science, explorations to recover female scientists and challenge an assumed lack of contribution by women have pointed to the increasing professionalisation and Darwinisation of science at the end of the nineteenth century. At this time, the rapid processes of institutionalisation combined with evolutionary arguments concerning women's lesser capacity for intellectual work to create a major barrier to women's participation. This has led some historians to lend a new importance to the domestic sphere and look for women scientists in the home, away from institutional contexts. This study aims to question and problematize both of these approaches.

Existing scholarship

There are few works of scholarship on women and mathematics that go beyond a straight-forwardly biographical approach. Alison Winter has written of the connections between mathematics and the female body in the case of Ada Lovelace in early Victorian England;[1] Margaret Wertheim has attempted a broader study encompassing Pythagoras to the twentieth century in an attempt to demonstrate the masculine, priestly

[1] Alison Winter, 'A calculus of suffering: Ada Lovelace and the bodily constraints on women's knowledge in early Victorian England', in *Science Incarnate: Historical embodiments of natural knowledge*, ed. by Christopher Lawrence and Steven Shapin (Chicago: University of Chicago Press, 1998), pp. 202-239.

construction of mathematics.[2] The latter study typifies a common approach to mathematics in assuming the ahistorical nature of the discipline and failing to account for changes in the configuration of the subject at different times. In part, this is a consequence of mathematics' resistance to sociological analysis; there have been far fewer attempts to offer insights into the social construction of mathematics as compared to the vibrant state of social studies of science.[3] Mathematics' claim to be absolute knowledge - permanent and unchanging over time - has reigned unchallenged until recently, leading to a neglect of the social and cultural implications of its production. Such historiography focuses attention on disembodied mathematical ideas at the expense of context and, as a result, offers only a limited account of mathematical change. Such an approach cannot, by definition, address many of the issues raised here, for example the changing relations between gender and mathematics, and science and mathematics, around 1900. One of the assumptions of this study is that mathematics is, indeed, informed by its social and cultural context (and that, in turn, mathematical ideals and practices spill over to inform the society and politics of their practitioners). It is concluded that, at the turn of the nineteenth century, pure mathematics became less conflicted with contemporary prescriptions of femininity, partly in response to the rise of professional engineering and science which defined itself via an active, virile masculinity. In this way, the idea that mathematics is, and always has been, configured as an innately masculine discipline is challenged, acknowledging that this gender 'colouring' is concerned with the culture of mathematics, not the fact that participation may be dominated by one or the other sex.

A recent publication which provides a social perspective on Cambridge mathematics, and which takes masculinity as one of its central themes, is Andrew Warwick's *Masters of Theory.*[4] Although Warwick is sensitive to the complex and often negative effects that the masculinised culture of competitive mathematics exercised on individuals, he does not focus his attention on women; instead his primary aim is an exploration of the

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[2] Margaret Wertheim, *Pythagoras' Trousers: God, physics and the gender wars* (London: Fourth Estate, 1997). Wertheim makes no distinction between mathematics and physics for the purposes of her argument.

[3] For the social construction of mathematics see, for example, David Bloor, 'Formal and informal thought', in *Science in context: Readings in the sociology of science*, ed. by Barry Barnes and David Edge (Milton Keynes: Open University Press, 1982), pp. 117-124; *Math Worlds: Philosophical and Social Studies of mathematics and mathematics education*, ed. by Sal Restivo, Jean Paul Bendegem and Roland Fisher, (Albany: State University of New York Press, 1993).

[4] Andrew Warwick, *Masters of Theory: Cambridge and the rise of Mathematical Physics* (Chicago: Chicago University Press, 2003).

education and cultural traditions of male 'wranglers'. By turning the spotlight to female mathematicians, this study will extend Warwick's analysis of tripos reforms at the end of the nineteenth century and reconsider aspects of his arguments connecting mathematics to manliness at this time.

There is a larger body of scholarship on gender and science than on gender and mathematics. In part this is because mathematical women have tended to be subsumed under the umbrella of 'women in science' in biographical anthologies and in important, more analytic, contributions from scholars such as Londa Schiebinger and Evelyn Fox Keller[5]. However, as this study demonstrates, the material processes, epistemologies, cultures and configurations of mathematics and science differed markedly around 1900 and to subsume women mathematicians under women scientists is to obscure, rather than illuminate, the experiences of both. At the end of the nineteenth century, the two disciplines were engaged in a struggle for status and influence which resulted in self-definitions and legitimations that relied on 'difference' from the other. Pure mathematics retreated into abstraction and prided itself on being 'uncontaminated' by the real world; in contrast, experimental science and engineering pointed to its utility in the real world as a generator of progress and technology, and as a source of explanation about nature. This study will explore how these differing configurations and histories affected the position of women and informed the intellectual product of each discipline. Recent case studies have revealed a more complex picture of women in science by uncovering previously 'invisible' women and following them into the laboratory.[6] One of the aims of this study is to add to this body of work by unpackaging the processes of institutionalisation and professionalisation to reveal the complex mechanisms of inclusion and exclusion.

[5] Londa Schiebinger, *The mind has no sex? Women in the origins of modern science* (Cambridge, MA: Harvard University Press, 1989); Evelyn Fox Keller, *Reflections on Gender and Science* (New Haven: Yale University Press, 1985).

[6] For example, Marsha L. Richmond, ' "A lab of One's Own": The Balfour biological laboratory for women at Cambridge University, 1884-1914' in *History of Women in the Sciences: Readings from ISIS*, ed. by Sally Gregory Kohlstedt (Chicago: University of Chicago Press, 1999), pp. 235-268; Paula Gould, 'Women and the culture of University physics in late nineteenth-century Cambridge', *British Journal for the History of Science*, 30 (2) (1997), 127-149.

Male-female collaborations

The nature of male-female collaborations in science have been explored by Pycior and others in their edited collection *Creative Couples in the Sciences*.[7] This study provides a taxonomy of such partnerships in the nineteenth and twentieth centuries and considers the ideological and practical negotiations which took place within the scientific marriages of couples working across various disciplines and cultures. Subjects include Nobel-prize winners Pierre and Marie Curie, astronomers Margaret and William Huggins, and physicists Albert Einstein and Mileva Marić. This significant study of 'cross-gender' collaboration alerts us to how important such partnerships have been as, 'aside from women's colleges, they were historically the single most important avenue for recruiting women to science and retaining them as active participants'.[8] As well as the seventeen partnerships to which a chapter is devoted each, the book contains a useful appendix of collaborative couples which underlines the frequency with which such partnerships have developed across a diversity of sciences. In an attempt to discover patterns of collaboration, the authors categorise their subject couples according to 'types' such as 'Peaks of collaborative success: The Nobelist Couples', 'A spectrum of mutually supporting couples', and 'Couples devolving from creative potential to dissonance'. However these divisions are not analytically comparable in the sense that some are based on the success of the research produced, and others on the quality (or lack of it) within the working relationship. Some couples could be placed in more than one category, a fact that is arguably an inevitable consequence of the fluidity and uniqueness of each couple's relationship.

The chapter by Sylvia Wiegand on Grace Chisholm Young and her husband has been grouped in another type of category, that of 'Couples beginning in student-instructor relationships' (a choice of classification which is questioned in chapter four). Wiegand addresses some of the issues raised in this study, including the nature of the Youngs' collaboration, the options available to mathematical women, and the way in which gender can be implicated in the allocation of credit for work

[7] Helena M. Pycior, Nancy G. Slack and Pnina G. Abir-am, eds, *Creative Couples in the Sciences* (New Brunswick, NJ: Rutgers University Press, 1996). See also Pnina G. Abir-am and Dorinda Outram, eds, *Uneasy careers and intimate lives: Women in science, 1789-1979* (New Brunswick, NJ: Rutgers University Press, 1987).
[8] Pycior, pp. ix-x.

produced jointly.[9] Although the latter is true in many instances, as *Creative Couples in the Sciences* illustrates, the associated idea that women required a male mentor as gatekeeper to their chosen discipline has become an explanation of first recourse in the history of women and science and, used in this way, it can obscure as much as it reveals. An exploration of the lives of the female subjects of this study suggests that a more adaptable model is often required, one which does not suggest female passivity or dependence and which allows the possibility of female initiation and leadership within male-female collaborations.

Trust in the production of science

Despite the increase in scholarship on women and science referred to above, gender has failed to play a part in an important recent debate within the social history of science which centres around notions of trust and the ways in which experimental findings become accepted as scientific knowledge. Shapin and Schaffer have argued that this process depends on a set of social conventions resting on relations of trust between disinterested gentlemen scientists. They attempt to 'show that the experimental production of matters of fact involved an immense amount of labour, that it rested upon the acceptance of certain social and discursive conventions, and that it depended upon the production and protection of a special form of social organization'.[10] Porter has placed more emphasis on the development of the concept of 'objectivity' and 'trust in numbers' which he interprets as replacing this reliance on the veracity and trustworthiness of the scientific practitioner.[11] Gender has been completely absent from this debate which has been conducted from a wholly masculine point of view. This limited perspective has served not merely to sideline women, but to remove them from the range of vision altogether. Yet distrust of gender was a crucial variable in the inclusion or exclusion of women within the scientific community; in addition assumptions about the gendered nature of intellect affected the reception and interpretation of women's scientific work. These issues became even more acute in the first decade of the twentieth century as the militant suffrage campaign served to generate controversy and discussion over woman's role in society and anxiety concerning her

[9] Sylvia Wiegand, 'Grace Chisholm Young and William Henry Young: A partnership of itinerant British mathematics' in Pycior, pp. 126-140.
[10] Steven Shapin and Simon Schaffer, *Leviathan and the Air-pump: Hobbes, Boyle and the experimental life* (Princeton: Princeton University Press, 1985), pp. 22-79 (p. 22).
[11] Theodore M. Porter, *Trust in Numbers* (Princeton: Princeton University Press, 1995), especially chapter 9: 'Is science made by communities?', pp. 217-225.

emotional and mental stability. For some, women's emotional nature and want of 'male' rationality (demonstrated by the violent behaviour of the militant suffragettes and explained by reference to evolutionary principles) clearly pointed to her ineligibility for 'objective' science.

Applying a social-study model to the development of mathematics also reveals that gender was implicated in the processes by which a piece of mathematics became accepted as valid at turn of century. With the increasing importance of a new form of highly abstract, pure mathematics which infiltrated from the Continent, what constituted validity changed. No longer was the worth of a piece of mathematics to be judged by its correspondence to, or utility in, the real world; instead mathematics became self-referential and qualifying criteria became internal consistency and the power to generate results, as well as subjective, aesthetic concerns such as beauty and simplicity. In this context, the reputation of the producer was central to whether his or her mathematics was accepted as part of the mathematical canon. It became essential to situate yourself as a mathematician of ability and gain the trust of your audience that this was so; as will be demonstrated in the succeeding chapters, this was a process difficult for women on both counts.

Pure and practical science

In a study seeking to contrast the differing configurations of mathematics and practical science around 1900 it is essential - but difficult - to define terms. The word 'practical' has been used in preference to 'applied', as the latter has a particular relevance to the history of chemistry, a discipline which exhibited a symbiotic relationship between intellectual and 'hands-on' labour from its earliest days.[12] During the nineteenth century all areas of science witnessed a growing distinction between intellectual labour and its practical or industrial application, a distinction which intersected with notions of class and was key to the identities of male and female scientists (as the experiences of Hertha Ayrton and Grace Chisholm Young will demonstrate). Similarly, the scope of this study does not extend to the biological sciences as these have their own histories, aesthetics and gender colourings which require separate consideration. The problems of locating the boundaries between science and technology, science and engineering, or mathematics and 'physical'

[12] See Jan Golinski, 'Chemistry', in *The Cambridge History of Science: Volume 4, Eighteenth-Century Science*, ed. by Roy Porter (Cambridge: Cambridge University Press, 2003), pp. 377-396.

mathematics, is illustrated by the lack of consensus on the issue and, in one sense, the search is fruitless as the concepts themselves are fluid and subject to historical change. All that can be maintained with any certainty is that the terms imply a certain hierarchy and that, in the decades surrounding 1900 at least, science represented the privileged side of the science-technology relationship. The introduction of mathematics adds another level of complexity to the issue. Where does mathematics end and mathematical physics begin? When does mathematical physics become the same as practical science or experimental science? And when does the latter turn into technology/engineering? These distinctions can become unclear whatever defining criteria are used (aims or motivations, working practices, theory or experiment) and, for example, engineering can result in discovery (often taken as the hallmark of 'science') and experimental science can, and often does, result in technology.[13] Around 1900, many members of the scientific community, taken in its broadest sense, combined roles as researcher with producer of technology, or engineer with experimental investigator; this was in keeping with the unfolding nature of these disciplines and reflects the processes of specialisation. It did not follow, however, that all occupations were regarded as equally valid or had similar cultural meanings; tensions and hierarchies, often informed by class, rivalry between new and older traditions, or accusations of commercialism, could and did arise. There is evidence that issues of categorisation were no less confusing to contemporaries intimately connected with the rapidly-developing fields of mathematics and science at turn of century. The scientific journal *Nature* alluded to the problem in November 1900 when it reported on the modern 'cleavage in mathematical thought'. *Nature* went on to explain that, at the recent Physical and Mathematical Congresses held simultaneously in Paris, any follower of Maxwell and Kelvin uninterested in the new mathematics of analysis 'must turn to the physical sector for the interest he requires'.[14] It seems clear that contemporaries made distinctions between (and moral judgements on) the pure and practical sciences, even if boundaries remained ill-defined and unstable.

For this study, a working distinction will be made between predominantly laboratory-based investigations which will be subsumed, for ease, under the umbrella 'practical science' and mathematics as predominantly desk-based. While not implying any rigid categories, this

[13] Otto Mayr, 'The science-technology relationship', in Barnes and Edge, pp. 155-163.
[14] *Nature*, November 8 1900, News, p. 28.

does reflect crucial differences in material and epistemological practice; it also helps to reveal important historical differences between the two in configuration and self-identity which were central to the participation of women. As will be discussed later, mathematics did not professionalise in the same way as the sciences and did not transfer to new spaces of practice such as the laboratory - places where, as this study will show, any hint of femininity came to be seen as incongruous and inappropriate.

Grace Chisholm Young and Hertha Ayrton

The experiences of mathematician Grace Chisholm Young (1868-1944) and physicist and electrical engineer Hertha Ayrton (1854-1923) will be used as a window through which to view the changes in mathematics and science which occurred in the decades surrounding 1900. Similarities in their life trajectories make the women viable and productive objects of comparison. They both studied, in succeeding decades, for the mathematics tripos at Girton College Cambridge, and, unusually for their time, they chose to be practitioners of their discipline, not teachers of it. Furthermore, each woman's politics and philosophies were intimately connected with her science; this was manifested in their intellectual product, the constituency for their work, their views on equality between the sexes and their marital/collaboration strategies. That they both married men who pursued the same career as themselves facilitates an analysis of the politics of collaboration between the sexes which throws light on major differences in attitude between mathematics and practical science at this time. It will be argued that both of these disciplines came to identify themselves in opposition to each other and that this had a marked impact on the development of each. Practical science and engineering became configured as an active, virile and manly pursuit while mathematics, in part in an effort to distance itself from the new, professionalised sciences, accelerated its flight into abstraction and became more 'feminised' in language and practice. As this study of the two women will demonstrate, issues of gender became caught in the crossfire.

Sources

To facilitate a better understanding of the material, cultural and social issues surrounding women in mathematics and science it has been necessary to adopt an inclusive approach to sources. The material used in this study extends beyond institutional records, memoirs, the testimony of individual scientists or mathematicians and their specialist output, to include literary, fictional, journalistic and photographic/pictorial sources too. Only English-language sources have been referred to during research for this project. There are additional accounts of the early female students who studied at Göttingen University, and other literature referring to the school of mathematics (in particular on Felix Klein and David Hilbert, the professors who made a key impact on the development of Göttingen mathematics) available in German. Primary sources for the two women are not comparable in quantity or quality and this has presented difficulties for this study. For this and other reasons, both sets of information have required careful contextualisation of evidence and, where possible, the addition of supporting data.

Grace Chisholm Young, together with her husband William Henry Young, left a major personal archive, almost all of which is held as an extensive collection by the University of Liverpool. This includes in excess of one thousand letters between the couple, correspondence with mathematicians and others, personal and mathematical notebooks, diaries and autobiographical writings. The Youngs undertook a self-conscious preservation of material that reflected their belief, informed by eugenic sympathies, in the importance of intellect and the existence of a natural, 'best-bred' elite. (It will be illustrated later how this belief was intimately connected with their mathematics.) A conviction that they were a part of this special 'aristocracy' made keeping a record of their lives essential. Although it is not suggested that this was the only reason for their retention of all the ephemera of their lives, it was a tradition for Grace's family, the Chisholms, who had provided family data for Francis Galton when he embarked on one of his early studies of inherited talent. An understanding of Grace Chisholm Young's motivations in preserving so much about herself requires caution from any researcher using her archive unproblematically. In particular, her autobiographical writings, of which there are several versions relating to her years at Girton College, are romanticised accounts written some years later which tend to reconstruct her persona and events as she would prefer them to be. The difference between the public face that she presents here and that exhibited in her correspondence is significant.

By contrast, Hertha Ayrton's archive is less extensive and distributed widely. Apart from her published work and media reports, letters and memoirs exist in various locations in the UK and Paris and there are several collections of institutional and patent records relating to her too.

In the absence of any easily accessible, homogeneous body of source material, a main recourse for writers has been a memoir of Hertha Ayrton, published two years after her death, by her friend Evelyn Sharp.[15] Sharp had embarked on the book at the suggestion of Hertha's daughter Barbara Ayrton Gould[16] with whom she was in correspondence; Sharp then advertised on the letters page of *The Times* for any readers with letters or information about her subject to contact her.[17] Although long and comprehensive, Sharp's biography is at times at odds with other source material and is an uncritical celebration of her friend's life as 'physicist, suffragette, democrat and humanitarian'.[18] There is no doubt that Sharp was writing for a particular audience or that she had a specific feminist agenda to advance. Sharp was a journalist, writing for the *Manchester Guardian* and other papers, and a committed suffrage campaigner. She had met Hertha in 1906 when they both became members of Mrs Pankhurst's new Women's Social and Political Union. Sharp was imprisoned in Holloway on two occasions due to her militant activities; in 1912 she broke away from the Pankhursts to help found the United Suffragists and edit its journal *Votes for Women*. Sharp's strategy in her journalism and elsewhere was to convey suffrage ideas and ideals to the wider public[19] and Hertha Ayrton's life story was an ideal vehicle with which to convey both explanation and justification of the suffrage cause. (Sharp's biography was published in 1926, two years before women were eligible to vote on the same terms as men.)[20] Relying on Sharp's uncritical narrative of Hertha Ayrton as exceptional individual and pioneer of women in science has led some scholars to misinterpret and misrepresent Hertha's experiences, as this study will demonstrate.

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[15] Evelyn Sharp, *Hertha Ayrton, 1854-1923: A Memoir* (London: Arnold, 1926). Biographic accounts based largely on this include Marilyn Bailey Ogilvie, *Women in Science: Antiquity through the Nineteenth Century: A biographical dictionary with annotated bibliography* (Cambridge, MA: MIT Press, 1991), pp. 32-34; James J. Tattersall and Shawnee L. McMurran, 'Hertha Ayrton: A persistent experimenter', *Journal of Women's History*, 7 (2) (1995), 86-112; Marjorie Malley, 'Hertha Marks Ayrton (1854-1923), in *Women in Chemistry and Physics: A biobibliographic sourcebook*, ed. by Louise S. Grinstein, Rose K. Rose and Miriam H. Rafailovih (Connecticut: Greenwood Press, 1993), pp. 18-23.

[16] Barbara Ayrton Gould (1888-1950) was an active suffrage campaigner, became a member of the National Executive of the Labour Party in 1930 and in 1945 was elected as Member of Parliament for North Hendon.

[17] Evelyn Sharp, 'The late Mrs Hertha Ayrton', *The Times*, March 7 1925, Letters to Editor, p. 8. What happened to any responses is unknown; they have not been found included in any archive holding relating to Evelyn Sharp or Hertha Ayrton.

[18] Sharp, *Hertha Ayrton*, preface.

[19] See Angela V. John ' "Behind the locked door": Evelyn Sharp, suffragette and rebel journalist', *Women's History Review*, 12 (1) (2003), 5-13.

[20] Women over thirty years of age won the vote in 1918, at a time when the age bar for men was twenty one. In 1928 women gained the vote on the same terms as men.

Thesis structure

The following chapters explore the changing nature of mathematics and practical science in the decades surrounding 1900, illustrating that gender was a central element in each discipline's self-identity. Gendered assumptions informed the ways in which each discipline developed in relation to the other and had a crucial impact on the participation of women. Throughout this study Hertha Ayrton and Grace Chisholm Young will be referred to by their first names. This simplification makes it easier to distinguish them from their spouses and, in Hertha's case at least, reflects a desire that she often articulated to retain a separate identity from her husband.[21] It is not intended here to valorise these women or present their lives within any kind of 'breakthrough' narrative. Such approaches simply invert the 'great men' approach to the history of science and serve to obscure the real issues that women faced. As a result, the following chapters are not concerned (centrally at least) with the legacies that Hertha and Grace left to science or mathematics; instead the focus is on the negotiations that they needed to make in order to contribute to, and be a part of, their respective disciplines.

Although this study is not structured as a chronological or biographical narrative, chapter one will serve as an introduction to Hertha and Grace and concentrate on the experiences of women studying for the Cambridge mathematics tripos at Girton College. Issues surrounding the tripos training regime will be examined and it will be shown how notions of gender informed both the coaching of the female students and how their 'success' was given meaning. At Cambridge at this time, the seeds of an antagonism can be found between mathematics and the natural sciences tripos, the development of which will be traced in succeeding chapters. Chapters two and three follow Grace to doctoral study at the University of Göttingen in Germany, and Hertha to Finsbury Park Technical College and the Central Institution in South Kensington. Here the accelerating opposition between practical or experimental concerns and pure mathematics will be more clearly delineated and the very different position of women within each discipline exposed.

Chapter four examines the partnership of Grace and her husband William Henry Young, analysing the politics of their collaboration and

[21] Hertha always called herself 'Mrs Hertha Ayrton' instead of the conventional 'Mrs William Ayrton'.

exploring how their marital and work strategies connected to their conception of mathematics. Issues surrounding the relative contributions of each member of the partnership will be addressed and it will be shown how gendered assumptions about women and mathematics have led to Grace's input being misrepresented and downgraded. A comparison of this chapter with chapter five illustrates the different material practices and cultures of the pure and practical and how these differences were crucial to women. Hertha's experiences in the laboratory will be contrasted with the growth of an active, heroic culture around the experimental space which gave it a specifically masculine colouring. Chapters six and seven attempt a broader analysis, seeking to place both women within the context of their disciplines and identify patterns of involvement for women as a whole. Grace's participation will be assessed with specific reference to the London Mathematical Society; Hertha with reference to the Royal Society. This facilitates an understanding of the very different configurations of science and mathematics, as well as an insight to why the experiences of Grace and Hertha differed in terms of the nature of their participation and the acceptance of their work.

To conclude, it will be argued that Grace's and Hertha's careers illustrate competing threads in science and mathematics around 1900 which were manifested in differing conceptions of intellect, legitimation and gender. Hertha can be interpreted as representing a new, middle class, materialistic and meritocratic conception of science. Grace represents an older, romantic tradition of mathematics as an elite occupation for special intellects. Although both were welcomed at one level into their respective communities, feminine prescriptions and mechanisms to retain existing gender hierarchies were central to the practices and assumptions of both disciplines. Indeed, gender was one of the battle grounds upon which the pure and the practical carried out their struggle for influence, status and legitimation.

'.....the glamour of 'probably a wrangler' about her'[1]
Studying for the Mathematics Tripos at Girton College, Cambridge

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Emily Davies, founder of Girton College, the Cambridge College of higher education for women, observed in 1868 that 'the best girls' schools are precisely those in which the 'masculine' subjects have been introduced'.[2] The subjects that she was referring to were mathematics, Latin and Greek. When it came to the contentious issue of higher education for women, Davies was convinced that only if women succeeded in subjects held to be prestigious for men would their educational achievements be recognised as equally valid. She shunned any idea of a special system or curriculum for women because, to opponents of women's higher education, 'different' would automatically mean 'inferior'. Davies put her vision into practice the following year when she opened a residential college for women at Hitchin, a location that offered seclusion yet accessibility by being just one hour's train ride away from Cambridge. As the College began attracting more students, it moved to a new purpose-built facility at Girton. Located some four miles distant from Cambridge, this new building retained the privacy that propriety demanded while at the same time easing journey time to and from Cambridge for the male fellows who came to teach the women. Here Davies encouraged her students to study for the most highly-regarded triposes, especially mathematics, a subject that had long been a symbol of masculine success and which was to remain the elite Cambridge degree until the 1890s. This highly-competitive examination, a test of both physical and mental endurance, required students to compete in open-ended examinations, held over a number of days, to solve progressively harder problems. Preparation required candidates to be 'trained like racehorses' as the tripos 'rivalled the Newmarket races, and the bets on the outcome were just as keen'.[3] As befits such a competitive sprint, students were then individually ranked according to

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[1] Liverpool University, Special Collections and Archives (LUSA), Papers of W.H and G.C. Young (Young Papers) D140/12/22 (Grace's autobiographical notes).
[2] Emily Davies, 'Special systems of education for women', in *The Education Papers: Women's quest for equality in Britain, 1850-1912,* ed. by Dale Spender (New York: Routledge and Kegan Paul, 1986), pp. 236-241 (p. 239).
[3] Laurence Chisholm Young, *Mathematicians and their Times* (Amsterdam: North-Holland, 1981), pp. 267-8.

their performance in an order of merit which was announced publicly, before an often rumbustious crowd, at Senate House. After 1882, when papers were made available to women on a formal basis, female students were ranked alongside the men, although women had the right to examinations only, not to degrees. To be 'senior wrangler' (or first among the first class) was, for the man who achieved it, the route to opportunity and a coveted Cambridge fellowship.

A small collection of scholarship exists on the mathematics tripos at Cambridge University in the second half of the nineteenth century. Special attention has been paid to the development of teaching methods, its relationship to the natural sciences tripos, and the connections between the bodily and mental drill involved in preparing for the examination[4]. Little attention has been given to the experiences of women while training for the tripos and, for the most part, the history of mathematics, and of mathematicians, has been written as an unthinkingly gendered narrative. Even scholars producing a social or cultural history of the subject have often failed to include women in their analysis. With the focus of attention on male 'wrangler' culture, even Warwick's comprehensive and scholarly book marginalizes Cambridge's female mathematicians, some of whom won high places on the pass lists and went on to contribute to mathematical research.[5] Such approaches to the history of mathematics seem to rest on an assumption that the discipline is, by its very nature, intrinsically masculine. Towards the end of the nineteenth century such views were often not just tacitly assumed, but loudly argued. Scientists influenced by Darwinian ideas of sexual differentiation pointed to women's less evolved capacity for rationality or abstract thought; women were, it was argued, disadvantaged by their sex from grasping or manipulating the 'truths' of science or higher mathematics. In the opinion of one fellow of the Royal Society in a 1902 governmental report, women were simply not up to such work and 'education' could 'do little to modify her nature'.[6] One of the reasons that Emily Davies encouraged her students at Girton to take the mathematics

[4] For teaching see Sheldon Rothblatt, *The Revolution of the Dons: Cambridge and society in Victorian England* (Cambridge: Cambridge University Press, 1981); for relationship with the natural sciences tripos see David B. Wilson, 'Experimentalists among the mathematicians: Physics in the Cambridge Natural Sciences tripos, 1851-1900', *Historic Studies in the Physical Sciences,* 12 (2) (1982), 325-371; for bodily/mental training see Andrew Warwick, 'Exercising the student body: Mathematics and athleticism in Victorian Cambridge', in Lawrence and Shapin, pp. 288-326.

[5] Warwick, *Masters of Theory.* Discussion of Warwick's arguments will be found in chapter six.

[6] Henry Armstrong, FRS, in the Mosely Report on American Higher Education, quoted in Joan Mason, 'Hertha Ayrton and the admission of women to the Royal Society of London', *Notes and Records of the Royal Society of London,* 45 (2) (1991), 201-220 (p.212).

tripos was because this was the most prized degree for men and a subject generally held to be beyond the capabilities of women. When her students beat the men at mathematics it added ammunition to her argument for intellectual equality between the sexes.

Aims

This chapter aims to examine the Cambridge mathematics tripos with reference to women's participation. This will involve presenting the social context within which women approached mathematical study and exploring issues surrounding the tripos training regime that, prescribed for male students, could be ambivalent for women: rigorous mental and physical training, competition, and close study relationships with men. As well as mathematics having an impact on women and notions of femininity, women's participation in mathematics had a significant impact on the tripos itself and affected its relationship with the natural sciences tripos. These latter concerns will be addressed in more detail in chapter six, here the emphasis will be on the experiences of female mathematics students, the social context of those experiences, and the negotiations that were necessary to accommodate women (to a certain extent) within the mathematical life of the University. It will be demonstrated that women were not coached in the same way as men, that gendered notions of success were applied to students according to their sex, and that women's performance in the tripos adversely affected the prestige of the examination and contributed to reforms of the tripos introduced in the later years of the nineteenth century. This chapter will also serve as an introduction to the two women who provide a focus for this study and who both studied for the mathematics tripos at Girton in succeeding decades: Hertha Ayrton (1854-1923) and Grace Chisholm Young (1868-1944).

Hertha Ayrton

Hertha Ayrton, then Sarah Phoebe Marks, entered Girton College in October 1876, supported by the financial generosity of women's rights campaigner Barbara Bodichon and her circle of feminist friends.[7] She had lived a respectable but impoverished life with her Jewish immigrant family near Portsmouth before moving to London, at around nine years

[7] Barbara Bodichon (1827-1891) was one of the founders of Girton College; she had initiated and been involved in many feminist and educational projects including suffrage petitions, reform of the Married Women's Property Act, the Langham Place Group and the *English Woman's Journal.*

of age, to be educated alongside her cousins in the small school run by her better-connected aunt, Marion Hartog. According to her friend and biographer, Evelyn Sharp, Hertha first became interested in mathematics (and aware of Cambridge University) through the example of her elder cousin Numa Hartog. Numa, who had attended Trinity College, was the first Jew to attain senior wrangler status in the mathematical tripos (1869) and was admitted to his degree without having to take the usual religious oath.[8] Since receiving political rights in 1858, many of England's Jews had attained positions of status and with her move to London Hertha became part of a comfortable Jewish community which included the family of Sir Francis Goldsmid, the first Jew to become a barrister and an MP. Goldsmid was a financial supporter of Girton College (when Grace Chisholm entered Girton in 1889 she did so as Francis Goldsmid Scholar) and this is probably how Hertha became aware of the opportunities available there. Despite acceptance of those Jews who had become assimilated into middle class society, anti-semitism was on the rise in the late 1870s onwards, ostensibly in response to the arrival of poorer refugees from Eastern Europe. The coming of these immigrant groups coincided with the development of evolutionary approaches to science which codified and reified racial differences, creating a hierarchy of racial groups.[9] In 1905, the Government responded to escalating fears of an 'influx' with an 'Aliens Act' that limited Jewish immigration by excluding those without financial support or suspected of having a 'bad character'. Subliminal fear of the Jewish 'other' has even been implicated in the genesis of the vampire genre, which originated around turn of century, and it has been shown that representations of 'Dracula' and the anti-semite's 'Jew' are strikingly similar.[10] Whatever the reality of this, it is clear that the new

[8] Numa Hartog, 1846-1871. Despite being senior wrangler, he was prevented from taking a fellowship by his inability to subscribe to the required religious test. He was a prominent figure in the movement for Jewish emancipation until his untimely death from smallpox. Joseph Jacobs and Goodman Lipkin, 'Hartog, Numa Edward', in *Jewish Encyclopedia.com* <http://www.jewishencyclopedia.com>[accessed February 7 2005]

[9] By 1925, Karl Pearson, professor of eugenics at University College London, had illustrated with extensive statistics the inferiority of Jewish children with regard to intelligence, cleanliness of hair and tendency to breath through mouths, see David Albery and Joseph Schwartz, *Partial Progress: The politics of science and technology* (London: Pluto, 1982), p. 176. Jewish support for eugenics, based on its correspondence with traditional Jewish teaching, was also a thread around turn of century - see N.J. Zohar, 'From lineage to sexual mores: Examining Jewish eugenics', *Science in Context*, 11 (3/4) (1998), 212-231.

[10] Judith Halberstam, 'Technologies of monstrosity: Bram Stoker's Dracula', in *Cultural Politics at the Fin de Siècle*, ed. by Sally Ledger and Scott McCracken (Cambridge: Cambridge University Press, 1995), pp. 248-266.

'Jewish aristocracy' of which Hertha was on the periphery could, by its very conspicuousness, become a potential focus for hostility.[11]

Hertha was the first Jewish woman to attend Cambridge and there is some evidence that her Jewish origins had an impact on her experiences at Girton and was an issue for her at the start of her career. Hertha had been rejected initially by Girton's founder Emily Davies, probably in part because of the latter's Anglican sympathies. Davies' father and brother were clerics and most members of her family were distinguished by their evangelical piety. Although support for the establishment of Girton College had included Quakers, Unitarians and Jews, Davies required some religious observance from students. Daily prayers were said and Sunday services held, but these were not obligatory. At the time when Hertha entered Girton the celibacy restriction on fellows was still in place (repealed in 1882) and the monastic, religious traditions of the University were far from fully eroded. Despite reforming change, Cambridge was essentially a part of the Anglican establishment. Religious tests for higher degrees and membership of the University's governing body had been removed by 1871, but colleges still required (male) students to attend chapel until well into the next century. Davies wished Girton to be run on exactly the same lines as the men's colleges and, when new buildings were constructed in 1902, she insisted on the inclusion of a chapel - to the dismay of some of her secularising supporters.[12]

There are suggestions that Hertha was not fully comfortable at Girton; she wrote that at college religion was the great divide with the evangelicals ranged against the anti-clericals and a fellow student recalls her independence and disregard as to whether people liked her or not.[13] Hertha's 'bush' of thick, black, curly hair was an attribute coded semitic and was used as a defining feature by others. Even her patron, Barbara Bodichon, advised that when she went out to teach she should put her hair in a net as 'it would be worth £50 a year to you'.[14] As well as being representative of Jewishness, long, thick, dark hair was also a cultural symbol of wild, instinctive femininity and these kinds of representations jarred with Hertha's later efforts to present herself as a rational, empirical

[11] See John A. Garrard, *The English and Immigration, 1880-1910* (Oxford: Oxford University Press, 1971), pp.16-25.
[12] M.C. Bradbrook, *"That infidel place": A short history of Girton College, 1869-1969* (London: Chatto and Windus, 1969), p. 62.
[13] Sharp, *Hertha Ayrton*, p. 54.
[14] Ibid., p. 46.

scientist no different from her male colleagues. Hertha's dark looks would often feature in reports of her public lectures and may have enhanced her attraction for the press, at least in the early years of her career, as it added to her exoticness as a female scientist. When she read a paper before an audience of men at the Institution of Electrical Engineers Hertha was described as a little dark-haired, dark-eyed lady who 'created a sensation'.[15]

The second Jewish woman to attend Cambridge University was writer Amy Levy (1861-1889) who attended Newnham College and committed suicide at a young age. (Newnham was uncommitted to any religious view due to the secularising zeal of founder Henry Sidgwick, Cambridge reformer and campaigner against religious tests.) In her novels and short stories, Levy explored ideas of Jewish self-hatred. In 1886 she published an essay on *Middle Class Jewish Women of Today* asserting that, if they wished to pursue interests beyond the home, Jewish women had to break ties with their religion and its notions of family, race and the importance of marriage. Hertha is named as a high-achieving Jewish woman who traded broken ties for career success by renouncing her religion and marrying a gentile, the electrical engineer William Edward Ayrton.[16] Levy knew Hertha personally; they were friends and fellow members of the University Women's Club, so Levy's opinion on Hertha's choice to renounce Judaism was an informed one. That Hertha seems to have rejected participation in any of the Jewish philanthropic movements that proliferated at the end of the nineteenth century, despite her involvement in many other causes, adds weight to Levy's view. It is also strengthened by a fictionalised account of Hertha's life by her stepdaughter, Edith Ayrton Zangwill, which makes no mention of Hertha's Jewishness and implies a Christian faith.[17] It seems clear that Hertha did not embrace a Jewish identity and that breaking away from Jewish custom helped her in the feminist ways suggested by Levy; it also assisted her assimilation into middle class, scientific society. The completion of Hertha's change of name from Sarah Phoebe Marks seems to have taken place upon her

[15] Ibid., p. 136.

[16] Linda Hunt Beckman, 'Leaving the tribal duck pond': Amy Levy, Jewish self-hatred and Jewish identity', *Victorian Literature and Culture*, 27 (1) (1999), 185-201 (p. 195). However, there are examples of male Jewish scientists who did not relinquish their religion yet achieved success in the same scientific environs as Hertha, for instance Raphael Meldola (1849-1915), Professor of Chemistry at Finsbury Technical College. Women, as Levy indicates, have special responsibility for family and domesticity within Judaism and this makes it more difficult for them to combine a Jewish identity with work beyond the family sphere.

[17] Edith Ayrton Zangwill, *The Call* (London: Allen and Unwin, 1924). In this account Hertha/Ursula's family celebrate Christmas. Edith Ayrton married the Jewish critic and novelist Israel Zangwill.

marriage to William Ayrton - up until then she was still calling herself Sarah Marks on college records and on patent applications. The adoption of a new first name is usually attributed (perhaps with some romanticised rationalisation) to the influence of her friend Ottilie Blind. Blind is said to have given Hertha this new name after a Swinburne poem and because she resembled the Teutonic goddess Erda.[18] Why Hertha chose to adopt this name as a public identity (instead of as an affectionate name used by friends) is significant. The change underlined her desire to break away from, or at least render nominally invisible, her Jewish past. It can also be interpreted as representing a rejection of religious modes of explanation in general in favour of a new code of scientific rationalism (Sarah was biblical wife of Abraham and mother of Isaac). Hertha termed herself an agnostic which she claimed was the 'scientific' approach to religion as one 'cannot say that these things are not true, only that they have not been scientifically proved'.[19] In one of the few extant photographs of Hertha, a 1906 portrait of her in her home laboratory (a formal portrait that was carefully posed to commemorate her winning a Royal Society medal) a painting with a Christian theme is clearly visible in the top right hand corner (figure 5.2).[20]

Grace Chisholm Young

By the time that Grace Emily Chisholm arrived at Girton in 1889 the College was fairly well established with an increasing number of women seeking admission. A scheme of extension had commenced in 1886 and this had resulted in twenty seven new student rooms, bringing the total to one hundred and four. In Hertha's time facilities had been more modest, for example a library was not established at Girton until 1884. Relations with the University had developed too and now women were allowed access to examinations on a more formal basis and, in mathematics, were ranked alongside the men on the order of merit. Hertha had sat the mathematics tripos in 1880 when women were only allowed to do so unofficially and had to rely on sympathetic male dons to send them the papers. Had Hertha taken her examination a year later she would have been able to apply for a degree in 1921 when Cambridge began awarding women titular degrees only without membership of the University or

[18] Sharp, *Hertha Ayrton*, pp. 27-28.
[19] Ibid. p. 25. Thomas Huxley is credited with coining the term 'agnostic' in 1869 based on the view that, since nothing verifiable can be known about God, the only honest position was one of not knowing.
[20] This painting seems to be depicting the legend of Veronica, the pious woman of Jerusalem, who gave Jesus her handkerchief as he carried the cross.

voting rights; in 1948 Cambridge finally allowed women degrees on the same basis as men.

Grace was twenty one years old when she first entered Girton, the average age of entry of women to Cambridge prior to 1900. She was leaving an affluent middle class, well-connected family; her childhood had been spent in Hazlemere, Surrey, where she had been acquainted with the Tennysons and William Morris. Grace had been educated at home by her mother, née Anna Louisa Bell, who had taught all her children Latin, mathematics and music from an early age. Grace's elder brother Hugh had studied classics at Oxford, while her elder sister, Helen, was fragile having been disabled by polio as a child. In her romanticised autobiographical jottings, Grace presents herself as precocious from an early age, outshining her siblings and becoming the favourite of her father, Henry Chisholm, a gifted mathematician who had until retirement applied his talents to Weights and Measures in his Civil Service post as Warden of the Standards. Grace idolised her father as an intelligent, affectionate man who encouraged her mathematical interests, designed three-dimensional models with her and introduced her to geometry. Grace's mother and aunt were sympathetic to women's issues and the family were known to Emily Davies who arranged for Grace to try again for a scholarship after she had under performed in the Cambridge Senior Examinations due to illness.[21]

Different women, similar choices

Why did these two women from such different backgrounds aspire to Girton College? Martha Vicinus has demonstrated that from the beginning the women's colleges included a relatively wide range of young women from various levels of society. An obvious distinction was between those from wealthy families who attended for the sake of learning, and those who came in order to qualify for a better teaching post.[22] Grace wrote in her memoirs that she went to Girton because she had 'visions of intellectual cloisters like Plato's Athens' and yearned to meet 'the men of intellect of Cambridge' (when she finally arrived at Girton she still preferred the 'intellectual men' to the 'childish girls around her').[23] This romanticism and adulation of intellect as inherently

[21]LUSA, Young Papers, D140/12 (Grace's autobiographical notes).
[22] Martha Vicinus, *Independent Women: Work and community for single women, 1850-1920* (London: Virago, 1994), p. 39.
[23] LUSA, Young Papers, D140/12/23 and 22 (Grace's autobiographical notes).

male came to inform the culture of pure mathematics and was, for Grace, a factor in her later devotion to the discipline. Love of learning may have been just as important to Hertha, but her first need was to equip herself to support herself, her mother and an invalid sister. She had been working as a governess in London prior to her application to Girton College and, having found being a resident governess onerous, began to attract her own students prior to commencing her studies. Had they been students simultaneously, it is unlikely that Hertha and Grace would have been close friends. Despite attempts by Emily Davies to equalise conditions amongst students,[24] both Hertha and Grace report class divisions. For Grace, the influx of girls from the new high schools 'lowered the intellectual tone';[25] for Hertha, that some students looked down upon one of their fellows because of her shop-keeping background was a reason to proclaim her own origin from the rooftops.[26]

Grace achieved the equivalent of a first-class pass in part one of the mathematics tripos in 1892; she returned to score highly in the more specialised part two the following year, an advanced examination usually taken in a student's fourth and final year at college. In response to a challenge from her brother Hugh who wanted to prove the superiority of an Oxford education, after their success in part one of the tripos, Grace and fellow student Isabel Maddison[27] sat for the final Honours School of Mathematics at Oxford where, according to family legend at least, Grace obtained the highest mark for all students at Oxford that year. Grace's participation in the Oxford examination was purely an informal arrangement and her achievement did not enter the record book. However the fact that Grace and her fellow student were allowed to sit the examination is indicative of women's marginal (even inconsequential) status at Oxford and Cambridge at this time.

Hertha gained a disappointing third in the mathematics tripos in 1880 and did not go on to part two as this specialist extension examination

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[24] LUSA, Papers of Mrs R.C.H. Tanner (Tanner Papers), D599/6 (Grace's autobiography). Grace records that she was unable to purchase tea or other items for personal use at Girton, 'the principle of the College being that all students are on an equal footing and that richer students could not obtain privileges over poorer ones by paying for them'.

[25] LUSA, Young Papers, D140/12/22-23 (Grace's autobiographical notes).

[26] Sharp, *Hertha Ayrton*, p. 64.

[27] Isabel Maddison (1869-1950). After becoming a wrangler in the mathematics tripos of 1892, Maddison joined Charlotte Angas Scott at Bryn Mawr to undertake doctoral study (supervised by Scott) where she won a fellowship to study abroad and joined Grace at Göttingen. Maddison returned to Bryn Mawr, completed her doctorate in 1896, and took a post on the staff where she remained until retirement.

was not available at that time. Like many of the early students, she was ill prepared for university as she had not benefited from the preparatory education, similar to that available in boys' public schools, which was beginning to be offered by the end of the following decade in the new high schools for girls. The growth of these schools was in part fuelled by the growing availability of teachers from the new women's colleges. Hertha had spent time away from Girton due to illness and, while there, preferred to study in the morning and spend the afternoons engaged in more practical work. While still a student she had devised a sphygmometer (device for measuring the pulse) which was to be the first of several inventions for which she took out patents during her life.[28] Hertha's leanings to technology and invention prompts a question as to why she did not choose natural sciences instead of mathematics. The culture at Girton, informed by Emily Davies' desire to prove that women could do just as well in the difficult 'masculine' subjects, encouraged women to choose the prestigious mathematics tripos over the newer natural sciences. During Hertha's time at Girton, the latter tripos was still in the process of building a reputation, even though it had first been offered in 1851.

Although this privileging of mathematics had lessened to a large extent by the time that Grace arrived at Girton, the mathematics tripos was still regarded as somewhat 'special'. Such was its reputation that any woman perceived to be on course to be a mathematics wrangler was said to have a certain 'glamour' about her (when Grace used this term she was referring to Isabel Maddison). In the closing decades of the nineteenth century, physical scientists were engaged in challenging an academic hierarchy which placed mathematics at its pinnacle and were organising themselves into a profession. At a time when women's intellectual capacity was doubted by tradition and the new evolutionary sciences, the last thing that the natural sciences wanted was women to join them and undermine their growing status. Although the mathematics tripos was still an important route into scientific research, in the late 1870s and early 1880s this 'unintentional collusion' helped limit women's opportunities for participation.[29]

[28] This consisted of a watch spring fastened over the artery on the wrist with a marker (paint brush) attached to the other end of the spring which oscillated with the pulse. When a paper was pulled across the marker/paint brush at a uniform rate the pulse was recorded.

[29] See Sara Delamont, *Knowledgeable Women: Structuralism and the reproduction of elites* (London: Routledge, 1989), pp. 109-110.

Mathematics and femininity

But there were other reasons why the study of mathematics could be viewed as an appropriate discipline for women. In the last two decades of the nineteenth century an affinity developed between mathematics and ideals of femininity as, at Cambridge, natural sciences increasingly became the first choice for men in preference to mathematics (in the first years of the twentieth century up to twice as many men sat the natural sciences than the mathematics tripos). A mathematical education had long been the chosen route of the elite to prepare their sons for positions of power and privilege in society. Mathematics, along with classics, had been seen as central to a 'liberal education'; an education which aimed to aid character formation and foster the development of the intellect, not to train for any particular profession or calling. Indeed, mathematics had long been emphasised for non-technical reasons as a symbol of class and signifier of good breeding and, for this reason, it has been called 'the Latin of the modern era'.[30] As turn of century approached, and it became more acceptable for men to train for a profession, the ideals of a liberal education, with mathematics at its core, became viewed as especially suitable for women. Supporters of female higher education reassured society that it need not worry about educated women deserting the family and motherhood, or pursuing unseemly public activities, as higher education would increase a woman's intellectual powers and make her a better wife and mother. As Emily Davies had reiterated shortly after the foundation of her new educational initiative: 'This, then, is the aim of the college - not to train women for this or that specific calling, but so to develop and discipline their powers that they may be ready for use for the common good'.[31]

As higher education for women became more solidly established in the 1880s and 1890s, at the same time there developed a discourse centring on women's purity and nobility and an expectation that they should be 'men's superior conscience'. It was for this role that women should be educated.[32] The idea of women's service, as part of a general acceptance of the ideals of feminine behaviour, was strong in the new colleges as the pioneers of women's higher education sought to deflect criticism from

[30] Herbert Mehrtens, H.J.M. Bos and Ivo Schneider, *Social history of nineteenth century mathematics* (Boston: Birkhäuser, 1981), p. 41.
[31] Quoted in James Orton, *The Liberal Education of Women*, 2nd edn (New York: Barnes, 1896), p. 299.
[32] Joan N. Burstyn, *Victorian Education and the Ideal of Womanhood* (London: Croom Helm, 1980), pp. 109-110.

their contentious experiment. If women's task was to provide moral guidance and promote self discipline and gentlemanly behaviour, mathematics, as constitutive of a liberal education, could be viewed as an ideal tool.

Mathematics could also be regarded as especially suitable for women for another reason: it held little threat of compromising a young woman's innocence or femininity as the subject did not require any 'unfeminine' knowledge of the world. In 1881, when debate was on going at Cambridge over the admission of women to examinations, the Vice-Chancellor of the University argued that the study of Greek authors was 'bad enough for men, let alone women'.[33] Similar concerns were evident in responses to a questionnaire, devised in the early 1890s, which asked lecturers for their experiences in allowing women to lectures. Respondents in classics, biology and geology complained that the subject matter of lectures had to be modified for mixed audiences; lecturers in natural science similarly reported that certain parts of the course had to be omitted, as they could not be discussed in the presence of ladies.[34] Mathematics' use of a specialised symbolic language reinforced its remoteness from any unpleasant aspects of the world which could be deemed unfit for feminine ears. In addition, the use of formal symbols, and the objectivity that such symbols were believed to represent, relieved women of the need to take on uncomfortable and 'unfeminine' authority in their use of language. Women who were anxious about competing with men in the public sphere, or did not want their private personality to intrude on their work, could take refuge in mathematics' de-personalised notation and procedures. Grace, for example, was often reluctant to expose herself to public view; she characterised personal publicity as 'unwholesome' and confided to a friend in 1894 that she wished her 'private personality kept as much as possible in the background'.[35]

Despite aspects of mathematics that could make the subject a comfortable choice for women, there was still much debate as to whether the discipline was too hard for the female sex or detrimental to femininity and health. As late as 1912, the mathematics mistress of

[33] Quoted in Jean Barbara Garriock, *Late Victorian and Edwardian Images of Women and their education in the popular press with particular reference to the work of L.T. Meade* (unpublished doctoral thesis, University of Liverpool, 1997), p. 40.
[34] Rita McWilliams-Tullberg, *Women at Cambridge: A men's university - though of a mixed type* (London: Gollancz, 1975), p. 124.
[35] LUSA, Young Papers, D140/8/18 (Grace correspondence, January 22 1894).

Roedean, the celebrated high school for girls, argued in the Association of Mathematics Teachers' Journal that mathematics was of little practical use and 'too difficult for the average girl'. The previous year Sara Burstall, Headmistress of Manchester High School for Girls, claimed that 'even a moderate degree of success in mathematical study ... can only be attained at an excessive cost, in time, energy and teaching power'.[36] Burstall maintained that mathematical study should be kept at a minimum for girls, not least because of the 'hardening influence' it may have on their femininity.[37] Mathematics, she seemed to be implying, with its logical processes and cold unemotional reasoning, may tempt girls to ignore their feelings and neglect feminine ideals of service. Such views were often grounded in the Darwinian sciences which became increasingly influential during the last decades of the nineteenth century. Medical and scientific practitioners, seeking to explain gender difference by way of biological fact, pointed to woman's lower position on the evolutionary scale, greater subjection to emotions, frail physical constitution due to the demands of her reproductive system, and consequent decreased capacity for intellectual work. Mathematics had traditionally been viewed as too abstract and demanding for women; opponents of female higher education now reified this belief and placed it on a scientific footing. For example, from 1889 through the first decade of the twentieth century Patrick Geddes (a biologist who had trained with Thomas Huxley) and Arthur Thompson lobbied against higher education and a broader social role for women as 'what was decided amongst prehistoric protozoa cannot be annulled by an Act of Parliament'. They foresaw 'ruinous effects' if women competed alongside men and argued from biological 'fact' that men were the stronger, more intelligent sex and that women were less robust, yet more passive, sympathetic and affectionate.[38]

Such views were by no means universal however, and as women succeeded at college with no ill effects such arguments began to lose their credibility and power to cause anxiety. In 1884 Edwin Abbot, a headmaster and strong supporter of female education, published a mathematical social satire in which he parodied the resistance to

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[36] Geoffrey Howson, *A history of mathematical education in England* (Cambridge: Cambridge University Press, 1982), pp. 173-4.

[37] Quoted in Carol Dyhouse, 'Good wives and little mothers: Social anxieties and the schoolgirl's curriculum, 1890-1920', *Oxford Review of Education,* 3 (1) (1977), 21-35 (p. 25).

[38] See Margaret Burney Vickery, *Buildings for Bluestockings: The architectural and social history of women's colleges in late- Victorian England* (Newark: University of Delaware Press, 1999), pp. 152-155.

women's education and the tenets of social Darwinism. Abbot's aim was to challenge what he saw as injustice (or sexism, to use a modern term) in contemporary society by taking such views to their logical extreme and so illustrating their absurdity. Based on the notion of the fourth dimension derived from non-Euclidean geometry, in *Flatland* women were represented as straight lines because they were incapable of education or rational thought; men were represented as geometrical shapes with sides and angles - the more sides they had, the higher their social and evolutionary standing. Women had no angles because they had no brain power and were, therefore, inferior to even the lowest of the men - an isosceles triangle. *Flatland* proved very popular and many editions were produced into the next century.[39]

Training for the tripos

The drudgery of repetitive drill and memorisation required for success in the mathematics tripos has already been alluded to. Likening students to racehorses and the examination to the race was a common metaphor; stamina was important for open-ended examinations lasting several days and bodily training was just as important as mental drill. Every student hoping for success in the tripos was required to find a coach. Coaches had been the most important teachers at Cambridge at mid century; although their importance had declined in classics, they were still indispensable in mathematics due to the continuance of the order of merit. The reputation of a coach (and the fees that he could command) was measured by the performance of his students, drawn from varying colleges, and their ranking on the pass lists. Coaches wanted students with high potential; students wanted coaches with a record of drilling high-placed candidates. There is evidence that women were not attractive as students to coaches who sought to maximise their reputations. A coach's standing was dependent upon the performance of his students; that the women were often starting from a lesser state of preparedness than their male counterparts compounded coaches' fears that they may not do well. One leading coach of the time, Edward Routh, declined to train Charlotte Angas Scott who went on to be placed equal to the eighth wrangler in 1880 (unofficially as this was prior to women's inclusion on the order of merit).[40] According to Hertha, who was her fellow student at Girton, Angas Scott was third on the pass lists after the first three days of examinations but dropped position later due to 'not

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[39] Edwin A Abbot, *Flatland: A Romance of many Dimensions*, 6th edn (Oxford: Blackwell, 1950).
[40] Warwick, *Masters of Theory*, p. 281.

having read enough, the result of having read so very little before she came up .....[41] Even Philippa Fawcett of Newnham, who had been marked out as a high achiever before her placing 'above the senior wrangler' in 1890, had been refused permission by another top coach, Robert Webb, to attend his classes. Such was Webb's antagonism towards women that he maintained that if Fawcett beat his candidate, G.T. Bennett of Emmanuel, both he and his pupil would emigrate to the new University of Chicago.[42] Fawcett, daughter of Newnham pioneers Millicent and Henry Fawcett, had been groomed for stardom from an early age and, unusually for a woman, was as well prepared as the best men. She had been tutored from an early age at home, had attended University College London for five terms prior to her entry to Newnham, and was tutored while there by Ernest Hobson.[43]

Webb's refusal to coach Fawcett had more to do with propriety and concerns about having a woman in the coaching room than any fears about her ability. One of Webb's male pupils remembered that he had had 'a rough tongue' and that he had refused Fawcett because 'he considered that the presence of a lady in his classes would prevent that freedom of language necessary for teaching mathematics'.[44] The coaching room was a rough, competitive place that was inappropriate for a 'lady' and, moreover, her presence could cause unease, discomfort and concerns about correct behaviour amongst the men. As late as 1911 a book entitled *The Intellectual Life* had testified to the difficulty of authentic communication between the sexes due to the requirements of etiquette, requirements which were 'hereditary and instinctive' for men. These rules made it 'quite impossible for men to speak to ladies in the manner which would be intellectually most profitable to them' as 'we may not contradict because it is rude'. The author concludes that 'Men will never talk to women with that rough frankness which they use between themselves. Conversation with the sexes will always be partially insincere'.[45] Concerns such as these all too often resulted in women's exclusion from the coaching room of the top coaches who

[41] Sarah Marks, 'Abstracts from letters to Barbara Bodichon' (January 30 1880), *Girton Review*, Michaelmas Term (1927), 8-11 (p. 10).
[42] LUSA, Young Papers, D140/12/22. Bennett did indeed become senior wrangler that year and was beaten by Fawcett who was ineligible to take the title herself due to her sex. Webb did not carry out his threat to emigrate and eventually retired from coaching at Cambridge in 1902.
[43] Ernest William Hobson, 1856-1933, was a research mathematician as well as a well-regarded coach; he was in the forefront, with Grace Chisholm and William Young, in introducing the theory of functions to Cambridge.
[44] Rev. Dr. R.S. Franks, 'Mr Robert Webb', *The Times*, August 5 1936, Obituaries, p.14.
[45] Philip G Hamerton, *The Intellectual Life* (London: Macmillan, 1911), pp. 261-264.

typically ran large and regimented training regimes for their male pupils. One answer to these problems was to recruit women into the coaching role and there are suggestions that parallel systems were seen as a solution to questions of propriety as well as of access. After her high placement on the pass list, Angas Scott was told by one of her examiners that 'if she would stay in Cambridge she should have his sister to coach at once'.[46] Angas Scott did remain as a lecturer at Girton for a short while, as did Fawcett for nearly nine years.

Despite reforms to university teaching that lessened the power and standing of coaches in the latter decade of the nineteenth century, there remained a mythology surrounding the best-known coaches, usually based on their eccentricity, the robustness of their teaching techniques and the speed of their problem solving, that female tutors found hard to emulate. The position of the female don was not of an equal status to her male counterpart: they were poorly paid, isolated and had little say in the curriculum or governance of the University. For Grace, even in the 1890s, 'nearly all the head lecturers are men and, as for the female dons, they are chiefly there to quiet the anxiety of parents for their daughters and act as chaperones. Nobody with any pretensions coaches with them if they can help it'.[47] Coaches won work according to their reputation, based in part on the number of wranglers they coached; it was difficult therefore for female tutors, teaching comparatively few female students and with pastoral duties to perform as well, to compete in this arena. The reputation of female mathematics tutors was not high - in the 1890s Grace records rumours circulating that the coaching offered at Newnham by 'Miss Fawcett' was not good.[48] There is no doubt that the long-held associations of the mathematics tripos as a vehicle for testing manliness as well as mathematical skill posed a barrier to women being accepted as effective coaches. However this association was in the process of being eroded in the last two decades of the nineteenth century as increasing numbers of women were successful in mathematics, giving that examination a more feminine colouring while the mantle of masculinity passed to the newer natural sciences tripos.

The men who lectured and coached the women students, unsurprisingly, tended to be supporters of women's education and, often, critics of the tripos system too. Grace was tutored mainly by Arthur Berry of Kings

[46] Sarah Marks, 'Abstracts from letters to Barbara Bodichon', p. 10.
[47] LUSA, Young Papers, D140/34/55 (Grace's autobiographical notes).
[48] Ibid., D140/6/160 (Grace's autobiographical notes).

(1862-1929) who served on the Executive Council of Girton College and who, as Secretary of the University Extension Syndicate, moved to allow women lecturers in 1893. Arthur Cayley was active in the foundation of the 1869 lecture series for women which eventually led to Newnham College; he taught many of the early students including Charlotte Angas Scott.[49] Angas Scott attended Cayley's lectures in the 1880s and he was also instrumental in opening Grace's eyes to mathematics beyond the tripos by welcoming her, and a fellow student, into his home and taking them to a special lecture he was giving in Cambridge. Students were required to pay extra for attending these events however, but the less well off women could sometimes dispense with this expense by attending lectures as a chaperone - something Angas Scott, daughter of a Congregational minister, took advantage of.[50] Hertha's coaching, typically for early women students, was fragmented and she was taught by various tutors including Richard Glazebrook (1854-1935).[51] Despite being fifth wrangler in 1876, Glazebrook was critical of the tripos system at Cambridge for its separation of mathematics from experimental work; he shared Hertha's inclination to experimentation and at the time that he coached her was working as a demonstrator at Cambridge's Cavendish Laboratory. Given this preference, Glazebrook was not considered by ambitious candidates as one of the most sought-after coaches. Like Glazebrook, many of the coaches and lecturers who visited the women's colleges came with a reform agenda which made them hesitant to simply replicate the education that was given to the men. These 'youthful and enthusiastic young gentlemen .... were more concerned to advance general culture than to coach for exams' and this led to protest from Emily Davies and some of the early students.[52] Despite Davies' wish to see women coached to compete successfully with the men, there is evidence of tension in the coaching room between female students and their male tutors and signs that the teaching techniques used for women were different from those used for men.

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[49] Arthur Cayley (1821-1895) Sadleirian Professor of Mathematics at Cambridge, President of the London Mathematical Society 1868-70.

[50] Patricia C. Kenschaft, 'Charlotte Angas Scott, 1858-1931', *College Mathematics Journal*, 18 (2) (1987), 98-110 (p. 102).

[51] Richard Glazebrook, 1854-1935, became the first director of the National Physical Laboratory in 1900, a post he held for the next nineteen years.

[52] Bradbrook, p. 32.

Mathematics coaching: The difference of sex

There are many accounts left by male wranglers describing their experiences in the coaching room, both in memoirs and obituaries, which are alike in recalling the immense hard work required and the relentless need to compete with one's peers. These accounts collectively comprise a shared mythology, with communal terms of reference, which was used as a model and added to by succeeding generations. A.R. Forsyth, who graduated in 1881, recalled being trained by the legendary coach Edward Routh[53] - an experience which he described as 'a marvel even of physical endurance, let alone intellectual effort'. Routh's 'system' was to offer one-hour classes, three times a week, on alternate days during term time and the long vacation. Classes were attended by a crowd of some twenty ambitious young men who were required to complete exercises and solve problems between sessions, their answers graded and publicly displayed. Teaching was entirely devoted to how to frame an examination question and involved 'scribbling hard ... not a moment spent in diversion or extraneous illustration .... there (was) little leisure for thinking, because we were all being taught'.[54] In similar vein, Robert Webb laid claim to practically all the time and energy of his pupils and could be harsh with students who failed to meet his exacting demands.[55]

Women's memories of being coached seldom convey this sense of relentless pressure, or any indication of sharp words or recriminations. Unlike Routh's industrialisation of the coaching process with some twenty men in the coaching room, women were generally taught in pairs in a more gentle style. For the students at Girton days were highly structured and the avoidance of mental strain and undue competition was paramount. Hertha was restricted to five hours study a day[56] and Grace expected to attend just one lecture each day, in the morning or afternoon, completing no more than six hours work with nothing after 6pm.[57] She also records receiving one hour's coaching a day, three days a week. Control, not work to the point of exhaustion, was similarly a hallmark of Fawcett's methodical study regime. This was composed of 'six hours

[53] Edward J. Routh was renowned as a 'wrangler master'. He coached more than 600 students between 1855 and 1888 including 27 senior wranglers. A.T.Fuller, 'Routh Edward John (1831-1907)', *Oxford Dictionary of National Biography* (Oxford: Oxford University Press, 2004), <http://www.oxforddnb.com/view/article/35850> [accessed February 9, 2005].
[54] A.R. Forsyth, 'Old Tripos Days at Cambridge', *Mathematical Gazette*, 29 (1935), 162-179 (p. 173).
[55] Franks, 'Mr Robert Webb'.
[56] Sharp, *Hertha Ayrton*, p. 56.
[57] LUSA, Young Papers, D140/6/1-32 (Grace's autobiographical notes).

work, *very* rarely exceeded, plenty of regular exercise and always to bed at 11.0'.[58] Coaches were wary of pushing the women as hard as the men: while Forsyth records being coached at a 'wonderful pace .... not a moment was wasted.. (just) grim doggedness and unresting drill',[59] Grace recalls a more leisurely, although hardworking, pattern that included a break halfway through when the tea tray came in and she poured.[60] Grace was given problems to solve between lectures, but she did not experience the pressure of repeated, public competition against peers in mock examination papers (as was Forsyth's lot).

Relationships between coaches and the women who they taught could be uneasy; many of the young fellows were not much older than their pupils (for example Hertha was exactly the same age as her coach Richard Glazebrook) and, for women and men, being in such close proximity to a member of the opposite sex, especially in an academic context, could be unsettling. Although Grace's autobiographical account of her Girton years is romanticised and written with hindsight, her identification of a strong thread of novelty and tension within the female student/male coach relationship is plausible:

> It was quite a new experience ... to come into contact with these male lecturers. She had danced and played tennis with young men of her own age, but here she was seated at a long table with a young man, crammed full of that mathematical knowledge for which she thirsted, and who poured it out for her, at the end of a quill pen, without any touch of familiarity, for the space of an hour, three times a week.[61]

In addition to avoiding 'familiarity', the 'young men' had other strategies for coping with a difficult situation: one walked straight into the lecture room at Girton and, without any greeting or acknowledgement, proceeded straightaway with his lecture. Interaction such as asking questions was frowned upon, it could threaten the formality of the proceedings and it held up the class. If students got lost or did not understand, they asked a fellow student.[62] It was the College's job to appoint coaches (there was a small pool of tutors who would consent to travel out to Girton) but students could voice a preference for whom they had. The College acted as an intermediary and accounting point and, in

58 Margaret E. Tabor, 'Philippa Garrett Fawcett, 1887-1902', *Newnham College Roll Letter* (January 1949), 46-51 (p. 47).
59 Forsyth, 'Tripos Days', p. 174.
60 LUSA, Young Papers, D140/12/5.1 (Grace's autobiographical notes).
61 Ibid., D140/12/23.
62 LUSA, Tanner Papers, D599/6 (Grace's autobiography).

this way, saved women the awkwardness of having to arrange a financial transaction. Receiving payment for intellectual work could still be cause for embarrassment and even male students and coaches could suffer anxiety during the collection of fees. (For some coaches, the student was required to hide payment somewhere in the room so that both student and coach could pretend that no monetary exchange had taken place.)[63]

Competition and success maybe - 'feminine' modesty *always*

A desire to be seen as guarding against overwork, protecting their students' health and highlighting domestic over scholarly virtues, was reflected in a nervousness in showing women at work in contemporary representations of the new women's colleges. An article on Girton published in *The Idler* was typical in its photographs of empty laboratories, libraries, reading rooms and lecture rooms.[64] Competition was a key element of the Cambridge mathematics tripos; it was made manifest in the annual jubilation surrounding announcement of the lists and it informed the close relationship that was perceived between competitive sport and the examination. For women competition, especially with men, threatened feminine ideals of modesty and service; a concern to connect with the domestic in contrast to male competitive ideals was even reflected in the architecture of Girton. Instead of being built to mirror the men's colleges with their grand, confident, institutional designs, Girton's purpose-built premises relied instead on a domestic architectural model which featured inglenooks, bay windows and roof dormers.[65]

While anticipation of a high place in the mathematics tripos could give a woman 'the glamour of 'probably a wrangler', there was also ambivalence in the students' attitudes to success and even the most high-achieving female students were praised for 'never displaying their cleverness in the wrong way'.[66] Delivering a paper to the Girton Mathematical Club, Charlotte Angas Scott warned her audience against being tempted to 'win a name for yourselves' and, instead, encouraged them to develop a genuine love for mathematics.[67] Reflecting similar concerns, a contemporary student chose humility as Philippa Fawcett's

[63] Rothblatt, p. 234.
[64] Garriock, pp. 83-85.
[65] Vickery, pp. 12-39 (p.21).
[66] Garriock, p. 85 (referring to women at Newnham College in 1895).
[67] Charlotte Angas Scott, 'Paper Read before the Mathematical Club at Girton College, May Term, 1893', *Girton Review*, 36 (1894), 1-4 (p. 2).

most outstanding characteristic and praised her for being 'modest and retiring, almost to a fault ..... so as to appear like a very ordinary person'.[68] But reticence to compete with men was not so evident when it came to competing with each other or against another women's college. Grace's autobiographical notes are full of remarks (some not very generous) about fellow students' abilities, while Hertha felt it particularly unjust that Newnham students, unlike Girtonians, were not obliged to adhere to the same examination conditions as the men. To follow the men's programme required passing the Previous Examination (or Little Go) in the first year, which tested Latin, mathematics and Greek, and sitting the tripos examination within three years and one term. As Hertha complained to Barbara Bodichon about the 1879 tripos: 'Newnham has two students in, one has been up four years and hasn't taken her Little Go, so of course she will take the shine out of ours. I think it's horribly unfair .....'.[69]

Women's concern to present themselves as humble and unexceptional can be interpreted as a strategy to counter hostility against them, hostility which increased in relation to women's success. Rita Tullberg suggests that it was only in the 1890s, when women were revealed to be as able as the men, that resentment against them competing with the opposite sex at university increased.[70] This bad feeling culminated in the infamous and overwhelming vote by University Members against giving women degrees in 1897. It is also reflected in the differing accounts of Philippa Fawcett's 1890 success. Unlike the celebration which is the hallmark of reports in the women's college magazines, memoirs written by male mathematicians tend to represent her achievement as odd and treat it with amusement and indulgence. Her coach, Ernest Hobson, is remembered in an obituary as having 'enjoyed one theatrical triumph' by having the female senior wrangler as one of his pupils.[71] Another account recalls that this 'daughter of a radical economist and of a most militant feminist.... achieved unique fame in the annals of feminism' and 'ruined the life' of Bennett and his coach.[72]

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[68] Alice Gardner, *A Short History of Newnham College, Cambridge* (Cambridge: Bowes, 1921), p. 77.
[69] Sarah Marks, 'Abstracts from letters to Barbara Bodichon', p. 9.
[70] Tullberg, pp. 102-3.
[71] 'E.W. Hobson', Obituary Notices of Royal Society of London, (3) (1934), 239.
[72] Young, *Mathematicians and their Times*, p. 278. It should be noted that Philippa's mother, Millicent Fawcett, was not a militant feminist but a supporter of the law-abiding, conciliatory wing of the suffrage movement.

Intellectual labour - a threat to women's health?

The competitive mental exertion required of male students by their coaches was accompanied by a harsh regime of physical drill which was believed necessary for men to achieve the intellectual and bodily discipline needed to excel in the mathematics tripos. Warwick has charted the emergence of the elite mathematics student as a manly ideal in whom the rational mind and body were perfectly combined, an ideal which reached its zenith in the middle of the nineteenth century.[73] Although this ideal was losing some of its influence by the 1880s and 1890s, hard work, competitive study and regular physical exercise were still felt important to achieving top mathematical honours. However, these prescriptions were problematic for women and clashed with contemporary notions of femininity which accepted that women's bodies and minds were not as robust as men's. Opponents of higher education for women used medical and scientific arguments to warn that pushing women too hard could injure their reproductive systems and cause general ill health, in so doing threatening their child bearing capacities and, as a result, the well being of the nation and empire as well. Particular concern was caused by the medical theory of 'menstrual disability', a belief that spawned a condition coined 'anorexia scolastica' which was believed to be a debilitating thinness and weakness resulting from too much mental stimulus, especially during menstruation.[74]

Pioneers of higher education took these warnings seriously. When Henry Maudsley published his oft-quoted 'Sex in Mind and Education' in 1874, arguing that women would suffer immense harm to their health by following study regimes similar to men's, Emily Davies and her group were worried that it could hurt their plans as 'there is much truth in it'.[75] William Withers Moore echoed Maudsley's views in his 1886 presidential address to the British Medical Association and there were calls for protective legislation for women of the educated classes analogous to that introduced for women working in factories and mines. In response, women's colleges at Oxford and Cambridge carried out joint research in 1887 on the health, marriage and childbirth patterns of former students. Their findings contradicted medical opinion in concluding that college-educated women were healthier and less likely to

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[73] Warwick, *Masters of Theory*, pp. 176-226.

[74] Patricia Vertinsky, 'Exercise, physical capability, and the eternally-wounded woman in late nineteenth century North America', *Journal of Sport History*, 14 (1) (1987), 7-27.

[75] Barbara Stephen, *Emily Davies and Girton College*, (London: Constable, 1927), p. 290.

have childless marriages than their less-educated sisters and cousins.[76] Significantly, in her reply to Henry Maudsley, Dr Elizabeth Garrett Anderson did not deny that nervous breakdowns and ill health were genuine problems but pointed to a different causation (want of mental stimulation) and reassured him that steps were being taken by reformers to develop girls physically and guard against such dangers.[77] Evidence of the concern over the health of women students (and the desire to reassure parents) can be gauged from the addition, in the first scheme of expansion at Girton in 1876, of an infirmary and suite of hospital rooms - facilities not deemed necessary in the men's colleges.[78] The importance attached to these issues can also be deduced from the references produced for women students: when Grace applied for a Fellowship at Cornell University, Girton's Mistress Elizabeth Welsh felt the need to stress her 'great vigour and energy both physically and mentally'.[79]

However, whereas strenuous physical exercise was deemed desirable for male mathematicians to prepare for the strain of the tripos, women took gentle physical exercise to guard against strain. At first the women took up gymnastics because it was thought that this would build up their delicate frames for study. Athleticism increased towards the end of the century, but women were still obliged to show restraint and conform at all times to 'ladylike' behaviour.[80] New activities such as hockey, golf and tennis were taken up with enthusiasm by students at the women's colleges, and it is significant that these were mostly 'domesticated' games which substituted rules, team work and co-operation for the aggressive individualism of running or rowing. Tennis was played by Hertha and Grace, and they both participated in drills of the Girton Fire Brigade - 'the first really masculine piece of organisation devised by Girtonians'.[81] Girton had a golf course in the 1880s; in the 1890s hockey was played, but only sedately, in full dress, away from male eyes. Sport was still overwhelmingly a symbol of masculinity; it was seen as an arena in

[76] Mrs Henry Sidgwick, *Health statistics of women students of Cambridge and Oxford and of their sisters*, (Cambridge: Cambridge University Press, 1890), p. 66. The collection of health statistics on students was a common response by women's colleges to medical anxieties; many studies of this kind, often generating reassuring results, were carried out in the United States, see Vertinsky, p. 20.
[77] Paul Atkinson, 'Fitness, Feminism and Schooling', in *The Nineteenth Century Woman: Her cultural and physical world*, ed. by Sara Delamont and Lorna Duffin (London: Croom Helm, 1978), pp. 92-133 (pp.106-107).
[78] Vickery, p. 20.
[79] LUSA, Young Papers, D140/6/38.
[80] Jennifer A. Hargraves, ' "Playing like Gentlemen while behaving like Ladies" : Contradictory features of the formative years of women's sport', *British Journal of Sports History*, 2 (1985), 40-52 (p.43).
[81] Bradbrook, p. 104. Hertha was one of the founders of the fire brigade in 1874.

which to develop courage and competitive instinct, both essential for success in the tripos. However, for male candidates physical failure in the face of the examination could also be interpreted as a sign of asceticism, abstraction and increased intellectuality. Warwick has written of 'funking fits' (collapses in the examination room) and notes that as early as mid century being pale and ill could be a sign of intellectual strength.[82] Similarly, Rayleigh remembers that J.J. Thomson could not stand up to the day after day physical strain of the tripos[83] and G.H. Hardy remembers missing out on showing his talent for sport at school as 'no one thought it worth looking for in the school's top scholar, so frail and sickly, so defensively shy'.[84] It is suggestive of the power of gender stereotypes that failure to stand up to the rigours of the tripos or competitive sport could be interpreted as a sign of intellectual strength among male mathematicians, while for women a purported lack of physical stamina was interpreted as symbolic of precisely the opposite. Both Hertha and Grace experienced bouts of ill health and headaches while students; by the end of the nineteenth century women were constantly defined by their reproductive bodies and for university women, singled out for their minds, there was a special tension that conflicted the requirements of rationality and femininity. Grace experienced this tension acutely, believing that she had 'had a certain career in the University world, and have managed to be one of the few women who do so without sacrificing health'.[85]

Gendered notions of success

Just as a failure of nerve or health was interpreted differently according to whether it was manifested by a man or a woman, so success in the tripos became associated with different, gendered explanations. As women became increasingly visible by winning high places on the order of merit, wrangler status became linked to a student's capacity for hard work but lack of originality; conversely, failure of men to achieve a top place could be rationalised away as indicative of mathematical creativity and a marked potential for research.[86] Similarly, originality in a

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[82] Warwick, 'Exercising the Student Body', p. 299.
[83] Lord Rayleigh, Robert John Strutt, *Life of Sir J.J. Thomson* (Cambridge: Cambridge University Press, 1942), p. 10.
[84] G.H. Hardy, *A Mathematician's Apology, with a forward by C.P. Snow*, 2nd edn (Cambridge: Cambridge University Press, 2001), p. 18.
[85] University College London, Library Manuscripts Room, papers and correspondence of Sir Francis Galton, 1822-1911, 196/9, (letter Grace Chisholm Young to Francis Galton, May 29, 1909).
[86] For example see Hardy, pp. 22-24.

mathematician was underscored by stressing that he 'never gave a thought to the tripos'.[87] The examination itself, with its requirement for speedy problem solving and the memorisation of formulae and model answers, became indicative of hard work and dull minds - a characterisation particularly aimed at women. This criticism became more endemic after the introduction of the specialist mathematics extension examination (part III, later to become part II) in the early 1880s. The idea that women were 'faithful followers', 'diligent' and 'paid meticulous attention to details' but were 'not capable of great creative work' had been a well-rehearsed argument since the 1870s.[88] This commonly-held assumption that women worked harder than the men to achieve their results, making 'the air' at the women's colleges 'tense', reflects this characterisation of women as conscientious but not original.[89] In 1913, a critique of late nineteenth century Cambridge argued that the fact that a woman (Fawcett) had already succeeded in beating the senior wrangler had destroyed the prestige of this award and contributed to the abolition of the competitive merit system.[90]

That women did well in the mathematics tripos, then, served to devalue the examination rather than to raise the reputation of the women themselves. Women were characterised as doing well due to their diligence but contributing nothing to research. Grace herself came to find the faults of the tripos 'repulsive' and, revealing a hint of resentment, wrote that 'if you do well at exams then you are not original .... Philippa Fawcett was not, who she beat, Geoffrey Bennett, was .... curiosity about unscheduled mathematics is depravity'.[91] These conflicting views on the merits of the tripos had antecedents from early in the century when the 'objective ranking' of mathematics students was facilitated by Charles Babbage's and John Herschel's introduction of symbolic analysis to Cambridge. This was a technique which attempted to industrialise the thinking process by reducing mathematics to skill in manipulating abstract algebraic notation.[92] While this conception of mathematical intelligence had the potential to democratise thinking by making it a skill that could be acquired, its opponents referred back to a more romantic

[87] This is a reference to Cambridge algebraist and Professor of Mathematics Arthur Cayley - 'a wonder in pure mathematics': Forsyth, 'Old Tripos Days', pp. 162-163.
[88] Sir Stafford Northcote, 1873, quoted in Burstyn, p 73.
[89] Young, *Mathematicians and their Times*, p. 267. See also Garriock, p. 84.
[90] I. Gratton-Guinness, 'University mathematics at the turn-of-the-century: Unpublished recollections of W.H. Young', *Annals of Science*, 28 (4) (1972), 367-384 (p. 373).
[91] LUSA, Young Papers, D140/6/55 and D140/2/2.1.
[92] William J. Ashworth, 'Memory, efficiency and symbolic analysis: Charles Babbage, John Herschel and the Industrial Mind', *ISIS*, 87 (4) (1996), 629-653.

view of intelligence as a special gift that was inherited, not learned. Although critics, such as William Whewell,[93] affirmed that mathematics should be applied to the world, they feared that abstract 'analytics' was trying to distort that world by forcing it to conform to a mistaken and confining structure which did away with any notion of inspiration or the divine. The arguments over the tripos at the end of century paralleled these earlier debates and also marked the beginning of an inversion of the issues that came to split mathematics into the pure and applied, each defined in opposition to the other. It will be argued in chapter two that the association of romanticism with abstract mathematics was a late nineteenth century phenomenon which inverted earlier hierarchies. When a new style of continental analysis was introduced to Cambridge around 1900, its supporters derived this new mathematics' legitimacy and moral currency from its irrelevance to the real world and from the fact that, like Art, it was the product of 'great minds'. Like Whewell before them, pure mathematicians warned that mathematics pursued solely for utility's sake, not for its own, devalues the practitioner and leads to social decay.

Conclusion

An exploration of the social practice of mathematics at Cambridge in the decades around 1900 illustrates that gender was a key determinant in the training provided for students of the mathematics tripos. Although an affinity between mathematics and femininity can be detected towards the end of the nineteenth century, it is clear that studying for the mathematics tripos was a very different experience for women than for men. Not only did the type and quality of coaching given to female students differ from that provided for their male counterparts, but the gendered meanings that became attached to women's achievement of high places on the pass lists resulted in this 'feminine' success being effectively devalued. This, in turn, had a reciprocal effect on the status of the tripos itself. Towards the end of century, the examination lost much of its prestige and reputation as an elite qualification due (in part) to an increasing recognition that women were able to compete successfully alongside the men and, in some cases, surpass even the best of them.

The culture at Girton among students studying for the mathematics tripos was informed by a pattern of tensions and attitudes that helped set the

[93] William Whewell (1794-1866) of Trinity College, Cambridge, a leading figure in early-mid nineteenth century science, mathematics and philosophy.

course for Grace's and Hertha's future careers. Grace's repudiation of tripos competition was key to her later espousal of elitist ideas concerning the male intellect, her sympathy with eugenics, her decision to put her mathematical skill at the service of her husband, and her belief in the absolute superiority of pure over practical mathematics. Hertha's experiences at Girton a decade earlier were more problematic; her love of experimentation and practical science did not make for an easy life at college at a time when the mathematics tripos, which had little experimental content at the time, was privileged above all others. Grace can be seen as representing the romantic traditions now attached to pure mathematics conceived as an abstract enterprise for gifted individuals; Hertha embraced the newer sciences, such as electrical engineering, which promised new opportunities as they began to challenge older hierarchies and made use of a practical, utilitarian and 'manly' mathematics. These hierarchies also intersected with notions of class: in a culture and educational context in which 'hand' and 'brain' had long been opposed, practitioners of engineering and the more practical sciences sought to raise the status of their professions and challenge the primacy of the 'pure'. Hertha's choice of the practical, and Grace's championing of the pure, can be interpreted as being informed by their very different backgrounds. It could argued that Hertha, as daughter of a Jewish-émigré watchmaker, would have acquired none of the prejudice against practical or manual labour that was one of the defining features of the educated, English middle class. The differences in the culture, material practices and gendering of pure mathematics and the practical sciences become more evident as we follow, in the succeeding two chapters, Grace to the 'Shrine of Pure Thought' in Göttingen and Hertha to Finsbury Technical College and the Central Institution at South Kensington. Despite their differences in outlook and choice, both women found themselves caged in by prescriptions of femininity which limited their participation within their chosen disciplines and affected their options, reputations and scientific credibility.

Chapter two

Grace Chisholm Young at the 'shrine of pure thought'

In April 1895, Grace Chisholm Young was 'wonderfully happy'. She had just received an honour that she had determined to 'move heaven and earth' to achieve - a prize which had required this young, unmarried mathematics wrangler from Girton to travel alone to a foreign country, with little knowledge of the language and culture awaiting her, without even an assurance that she would be given permission to pursue her goal when she arrived. But after much hard work Grace had finally achieved her aim. She had been awarded a doctorate in mathematics from the prestigious University of Göttingen in Germany. She had also, she was characteristically quick to claim, become the first-ever woman to receive such an honour in Prussia.[1] Grace was now keen to lose her amateur status, prove herself a fully-fledged mathematician and, as she had continually emphasised to counter her mother's anxieties over her independent daughter, earn her own living. Her devotion to mathematics had been 'vindicated' and she was ready to 'take my stand among mathematicians, out of the apprenticeship years, able myself to do work'.[2] And she had already begun. As well as receiving a guinea from the Home Reading Union for a paper on sound, Grace had had a *Vorträge* (seminar paper) accepted for publication by the Royal Astronomical Society[3] and her doctoral thesis was being prepared for the printers right now.

Yet the years ahead did not unfold in the way that this ambitious young mathematician, so confident in her intellectual abilities, had planned. During the next few years Grace struggled to achieve the future that she had hoped for and, finally, she decided to realign her priorities - an adjustment that contributed to a major bout of depression around New Year 1900. This woman who had resolved to earn an independent living acquiesced in putting her mathematical skills at the service of her husband and absorbing her mathematical personality into his. Two decades after achieving her doctorate, Grace was arguing that a woman,

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[1] Sophia Kovalevskaia had received a mathematics doctorate from Göttingen in 1874, but she had failed to sit the aural exam and the award had been granted 'unofficially' in absentia.
[2] LUSA, Young Papers, D140/8/60 (Grace to mother, April (n.d.) 1895).
[3] Grace Chisholm, 'On the curve and its connection with an astronomical problem', *Royal Astronomical Society Monthly Notices*, 57 (1895-7), 379-387.

'whatever her personal ambitions, really longs for a superior male mind' and yearns for the support of 'the complete man'. As a new 'Doktor' Grace had interpreted her success as a blow for the cause of women's education. She had praised Göttingen for the freedom and equality that it offered, unlike Cambridge, to women like herself. Now she warned that any girl who, 'having been granted entry into a society of intellectual boys, lets her personality intrude itself on their feelings, is sinning against the unwritten law of womanhood'.[4] Grace had achieved her doctorate in a subject generally held to be 'too hard' for women, yet just five years after her success she endorsed the views of Professor Max Runge of the Medical Faculty of Göttingen University who argued from evolutionary theory for women's lesser mental capacities.[5] How was such a transformation of viewpoint and behaviour possible?

Aims

In the last chapter evidence of the seeds of a rift between pure and 'physical' mathematics was introduced with reference to late nineteenth-century criticisms of the Cambridge mathematics tripos. Those seeking to reform that examination pointed to its privileging of repetitive problem solving over creative mathematics and one of their solutions was to introduce a specialist extension examination, open only to wranglers, that enabled candidates to specialise in either pure or applied mathematics. In this chapter the focus will move to the University of Göttingen in Germany, to where many critics of the tripos looked for the new mathematical thinking and research-led structure that they sought to use as a model to revitalise Cambridge. Grace's coach Arthur Berry had spent a year's sabbatical at Göttingen during which time he had been introduced to the new analysis and theory of functions, a highly abstract form of pure mathematics being developed at the University. His admiration for these new mathematical ideas was shared by other Cambridge reformers such as Ernest Hobson, Andrew Forsyth, William Young (Grace's future husband) and, later, Godfrey (G.H.) Hardy. Following on from the split in mathematics perceived at Cambridge, this chapter will examine the processes by which pure mathematics came to be configured in opposition to physical or practical mathematics, how its language and terminology became feminised, how ideas of male genius became central to its culture, and how all of these had implications for

[4] LUSA, Young Papers, D140/14/6 (This is a letter/personal account written by Grace for her daughter Cecily on Christmas day 1920. Cecily also studied mathematics at Girton College, Cambridge).
[5] LUSA, Young Papers, D140/6/392 (Grace to William Henry Young, November (n.d.) 1900).

women mathematicians. The discussion will be preceded by an exploration of Grace's experiences in Göttingen (where she returned to make her home and pursue research after her student years) which served to create severe tensions within her self-identity. Göttingen was a university town built on the reputations of its 'great men' of mathematics, a place where the spirit of romanticism still held sway and where hero worship of male intellect was one of the dynamics behind the development of the School of Pure Mathematics. Grace's natural elitist politics found their reflection within this community in which male intellectual transcendence was glorified and pure reason, in the cloak of abstract mathematics, was viewed as morally superior. The structure and culture of the mathematics department, and the type of mathematics pursued there, found their counterpoint in contemporary ideals of femininity. These ideals, in Germany even more than elsewhere, were rooted firmly in ideas of marriage and motherhood. Within this context, Grace found herself caged in by prescriptions with which she struggled to the end of her life.

Mathematical choices - the options for women

After receiving her doctorate, Grace returned home in order to consider the options available to her. She had resolved to remain unmarried and earn her living by mathematics, probably by gaining a fellowship at a women's college in America. She had already discussed the chance of a move to Bryn Mawr with her friends Isabel Maddison and Charlotte Angas Scott who were both on the staff of this new women's college.[6] Grace had applied unsuccessfully to Cornell University in the spring of 1893 and had considered an application to Chicago where her fellow doctoral student from Göttingen, May Winston, was based.[7] A fellowship at Göttingen University was out of the question. The admission of Grace and two American women in 1894 had been an exception initiated as an experiment by Friedrich Althoff,[8] the

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[6] Charlotte Angas Scott (1858-1931) studied mathematics at Girton but, because Cambridge did not award degrees to women, her BSc and DSc were awarded by London University. She went on to teach at Girton 1880-84 before travelling to Bryn Mawr where she became Professor of Mathematics until 1917 and President of the American Mathematical Society in 1905. Isabel Maddison (1869-1950) was Angas Scott's first doctoral student and later joined the staff at Bryn Mawr. Patricia C. Kenschaft, 'Charlotte Angas Scott, 1858-1931', *College Mathematics Journal*, 18 (2) (1987), 98-110.

[7] Mary (May) Winston (1869-1959) became the first American woman to receive a PhD in mathematics from Germany when she completed her studies soon after Grace.

[8] Friedrich Althoff (1839-1908) managed the Prussian universities from 1882-1907, leading them through a marked period of expansion and specialisation. It was through his vision, and his support of Felix Klein, that Göttingen became the most important mathematical centre in Germany. David E.

progressive official in charge of higher education at the Ministry of Culture in Berlin. He had charged Felix Klein to seek out foreign women who would return home after their studies and who would not compete with men for university posts. (German women had to wait until the early years of the twentieth century before they were permitted to matriculate.) Despite the difficulties of finding a suitable position, Grace was determined to follow the life of a teacher and 'celibate career woman', which is why she had refused a proposal of marriage soon after her return from Göttingen.[9] William Henry Young was a young fellow of Peterhouse College, Cambridge, who had coached Grace in mathematics briefly while her regular coach was on sabbatical. Although initially responding that she had cared for him only as a mathematician and not as a suitor, in the end Grace relented and they were married in June 1896.

The partnership seemed an ideal solution to both their needs. Pessimistic at ever finding a fellowship, Grace's correspondence reveals that she had planned that her marriage would allow her to pursue mathematical research, scaling the heights of creative mathematics, while her husband, with a suitably learned wife at his side, would carry on with the more mundane task of drilling students in the tricks they would need to compete successfully in the mathematics tripos. Yet by marrying and not becoming part of a community of mathematical and academic women, Grace missed out on an invaluable support network that may have helped her to retain her mathematical identity. Female teachers had organised themselves into associations which were becoming increasingly influential as a source of funds and support for women. The forerunner of the American Association of University Women (the Association of Collegiate Alumnae) had been established in 1882, while Emily Davies had set up an association for school mistresses as far back as 1867. When Charlotte Angas Scott transferred from Girton to Bryn Mawr College, she became the centre of a female support network from which many woman benefited, including Girton wranglers Isabel Maddison and Hilda Hudson.[10] Grace's comparative isolation became even more significant when it became clear that her new husband was not a man to

Rowe, ' "Jewish Mathematics" at Göttingen in the era of Felix Klein', *ISIS*, 77 (3) (1986), 422-449 (p. 427 and p. 435).

[9] Sara Delamont has identified two available lifestyles for graduates of the new colleges for women, the 'celibate' career woman who entered teaching and 'the learned wife': Delamont, p. 142.

[10] Angas Scott supervised six women doctoral candidates and thanks to her leadership ' women were far more active in the American mathematical community than they were later, earning 14% of the doctorates in mathematics awarded before 1940 as compared to only 5% in the 1950s': Kenschaft, p.105.

be overshadowed by his wife. Convinced that he was 'greater than the world around him', he was searching for a calling that would enable him to prove it. Grace presented it to him; in the words of their daughter, Cecily: 'It is as if she had been to him a mirror, in which he gradually saw himself and his real mind'. She goes on to describe how Grace and her husband forged a mathematical collaboration, their key aim to force recognition and a professorship for Young through publication. Cecily concludes by recalling that Grace had a special gift that she used to support her husband:

> This unique facility, which she had to the end of her life, of understanding and correctly interpreting the mind of others, enabled him to forge ahead with new ideas, building on without having continually to fill in the foundations, a job he could leave to her, and which we all know is terribly distracting and wearing in the act of creative work. When he 'laid down his staff' in 1924, it was in truth because she no longer had the stamina to help him.[11]

Whether this is an apt description of the Youngs' collaboration, or of the personal negotiations within their relationship, will be discussed in chapter four. Suffice to say that Grace's abandonment of her own mathematical ambitions brought her close to breakdown at New Year 1900 when she wrote, in tears, about her hopes for the future dying with the new century and the necessity of 'throwing overboard the old life' to be a wife and mother.[12]

Grace had written her despairing letter soon after the family's move to Göttingen. The couple had decided that, to be at the forefront of research mathematics, it was essential to live where all the exciting developments were taking place - and where advantage could be made from Grace's prestigious mathematical contacts from her days as a doctoral student. Göttingen was home to Grace from 1900 to 1908 and from where she managed the writing and publication of her own and her husband's papers. Young retained his teaching post at Cambridge and was therefore absent for regular, long periods of time. Grace's second sojourn in Göttingen found her in a very different situation from her previous stay; then she was a single woman of whom people held high mathematical expectations and an official member of the University. Now she was a young wife and mother (her son Francis had been born in 1897) and her relations with the University were dependent on the good will of her old

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[11] LUSA, Young Papers, D140/2/2.1.
[12] Ibid., D140/6/329 (This is a letter from Grace to Frances de Grasse Evans, a close friend from Girton).

professors and mathematical contacts. It is testimony to their opinion of her mathematical abilities that they welcomed her back into their community so warmly. She attended Göttingen's regular mathematical colloquium (an advanced seminar attended by professors and selected research students) as well as numerous functions at professors' homes which were part social and part mathematics. Grace's descriptions of these occasions reveal clues as to the tensions, questions of etiquette - and amusement - that could arise as to whether, and how, women could be treated as women *and* mathematicians:

> After dinner, Professor Klein was dreadfully afraid we should divide up into male and female, and he very much wanted us to talk to the men ..... He took my arm and carried me into the dining room to be smoked and all the men followed suit .... The Professor offered me the cigars with his quaint smile'.[13]

Grace also became a member of the Göttingen Mathematics Club. There is a photograph of this select group, taken in 1902, which shows Grace as the sole woman sitting at pride of place next to Felix Klein, the director of the Mathematics Faculty, who had been her PhD supervisor (figure 2.1). The other people ranged around her are a veritable 'who's who' of famous names from the annals of mathematics, including David Hilbert, Ernst Zermelo and Erhard Schmidt.

Conflicting roles: Woman, wife, mother - and mathematician

There is little doubt that being the only woman amongst such a select band of mathematicians appealed to Grace's vanity. In correspondence it is often recorded how she has attended a mathematical/social function and been the only 'lady' present, there 'as a mathematician and not as a woman'.[14] This distinction is a significant one because, despite the gentlemanly acceptance that Grace received from the Göttingen mathematicians, she found that sharing her time and devotion to mathematics with other duties created conflicts of self-definition within her and influenced the expectations of others. Ideals of female service were just as prevalent in Germany as they were in England and interest in 'the woman question' was especially intense around 1900 when a new German civil code was being formulated. This debate referred back to early nineteenth century German romanticism and stressed the

[13] LUSA, Young Papers, D140/6/34-46 (Grace's Göttingen correspondence, c. November 1893).

[14] LUSA, Young Papers, D140/6/267-328 (William Henry Young to Grace's mother, March 19 1899. The occasion referred to is a dinner held in honour of Felix Klein by the professors of the Mathematical and Physical Sciences at the University of Turin).

importance of what was called 'the eternal-womanly': a notion of immutable femininity, predicated on woman as instinctive mother and complement to man, which was viewed as distinctly German. There was broad consensus amongst women's groups that demands should be placed within the context of what is variously described as 'intellectual', 'organised' or 'extended' motherhood. One particularly influential figure in Germany was Ellen Key whose 1898 essay, 'Misused Women's Energy', suggested that most women would not find satisfactions in their jobs equivalent to those provided by raising their own children. The side of the debate that championed equal rights with men, or offered a critique of marriage, was much less vocal in Germany. Little protest was made about a law which, until 1908, prohibited women from attending public political meetings; and there was general assent amongst women's leaders to the teaching bar that required female schoolteachers to resign their posts on marriage.[15] A wife's support of her husband and family was expected to be her priority.

In experiencing tension between duty to marriage and motherhood or to a career, a female mathematician could be seen in much the same position as any other woman at this time who was engaged in an activity dominated by men. However, in the heady atmosphere of Göttingen, home to 'the greatest mathematical minds of the age', this stricture took on even greater urgency. Was it not imperative to support husbands who were great men doing great things for the world? Grace had surmised as much when she first arrived in Germany, remarking with approval that 'If it were not for the women, the learned men would not marry and live happily and usefully in the devotion of science'.[16] Grace was basing her comments on the wives of the professors whom she had come to know well. Felix Klein's wife, Luise, was a particular friend. She had been well schooled in providing the quiet domestic and personal support gifted men were supposed to need, as she was the daughter of the German idealist philosopher Hegel. Käthe, the wife of David Hilbert, was expected to act as secretary to her husband, writing out his papers in her

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[15] See Ute Frevert, *Women in German History: From bourgeois emancipation to sexual liberation*, trans. by Stuart McKinnon-Evans, Terry Bond and Barbara Norden, (Oxford: Berg, 1986), pp. 107-137.

[16] LUSA, Young Papers, D140/8/1-321 (courtship correspondence, October (n.d.) 1893). Similar attitudes have been uncovered by Sharon Traweek in her study of late twentieth century particle physicists: 'Several (wives) nodded vigorously when one well-educated wife in her late thirties told me she thought it selfish and silly for a high energy physicist's wife to pursue her own career. She thought that one could best contribute to society and civilization by providing as much support as possible for the work of people like her husband'. Sharon Traweek, *Beamtimes and Lifetimes: The world of high energy physicists* (Cambridge MA: Harvard University Press, 1992), p. 83.

best handwriting, and ensuring the harmonious environment conducive to his work. When Hilbert published his first groundbreaking paper on number theory in 1897, his friend and fellow mathematician Minkowski wrote in congratulation, also congratulating 'your wife on the good example which she has set for all mathematicians' wives'. Hilbert's biographer adds to this praise of Käthe by remarking that she never let 'tragedy hinder her husband from functioning as a scientist. Under her skillful (sic) management, the combination of fellowship, comfort and order necessary for Hilbert to work continued to be maintained ....'.[17] With these prescriptions of feminine behaviour before her, it is no wonder that Grace experienced insecurities about her role. These fears were articulated when her husband, who felt that his honour was threatened by a delay in publishing work, implied that his friends held the opinion that Grace was failing in her duty of helpmeet.[18]

There is no doubt that the Göttingen professors were unsure about how they should interact with Grace on social occasions, now that she was a wife and not a mathematics student. That her husband was not well known to them, and was absent for the majority of the time, allowed Grace greater presence as a mathematician than she might have had if her husband had been there to assume the role of intermediary. At the same time, her situation as a lone woman increased her personal relations with the female members of mathematicians' families who took her under their wing. Luise Klein, in particular, provided gifts and looked after Grace's son for whole days while she immersed herself in work. Ambivalence among male academics concerning the correct way to interact with a woman who was also a mathematical peer had also been apparent during Grace's earlier stay in Göttingen, at a time when she was a postgraduate student with an official presence at the university.

Female students at Göttingen

Women students were a novelty at German universities and their arrival in the early 1890s was all too much for one young Göttingen professor who, on having to visit a new female mathematics student (Grace), had 'had an attack of politeness through nerves'.[19] Although Grace was impressed by the comparative freedom of life as a student at Göttingen

[17] Constance Reid, *Hilbert* (London: Allen and Unwin, 1970), pp. 139-140.
[18] LUSA, Young Papers, D140/4/2 (Grace to Young, January 10 1901).
[19] Ibid., D140/6/43a (Grace to friend, October (n.d.) 1893).

(unlike Cambridge, the libraries, lectures and laboratories were freely available to her and she required a chaperone only when visiting one particular young, unmarried professor) female students were accorded special treatment and placed under special strictures. The women were not permitted to mix in the corridors with the male students before lectures but were to go to the professor's private room (Grace called this 'the sanctum') and he would take them in at the appropriate moment. This could be interpreted as a strategy to prevent hostility between regular students and the foreign women in their midst, more likely it was a way to preserve distinctions of sex and give the ladies due courtesy. Grace certainly saw it as the latter and often remarked in her letters home on the kindness and gentlemanly behaviour of the students and professors. Nonetheless, Grace and her two female companions sat at the back of the lecture hall (probably because they entered at the last minute) and Grace, for one, had difficulty in seeing the blackboard. However Grace did possess a key for the special mathematics 'reading room', an innovation of Klein's which was the only library of its kind in Germany. It housed a vast collection of the latest periodicals and offprints and was an important venue for mathematical interaction.[20] Special permission had to be sought for the women to take doctoral examinations from the Ministry of Education in Berlin and they were anxious as to whether this would be forthcoming. The sensitivity of the issue was underlined by the discretion Klein asked the women to use in talking about their studies before formal permission had been granted. They were allowed to attend lectures during this time and were assured that 'the curator will look the other way when we come in'.[21]

Klein was correct to pursue his plans with caution; male academics were not used to having women in their midst. Limited experiments with female 'auditors' at lectures (auditors were permitted by special permission, not by right, and denied student status) had been made from the 1870s onwards. The majority of these women were foreign, predominantly British, Russian and American. Grace and her two fellow American students had been admitted as part of another experiment in doctoral study for women. It was six years later, in the summer term of 1900, that German women were for the first time entitled to become fully-registered students and sit examinations. Heidelberg University was the first to yield; Prussia did not open its doors to women on a

[20] David E. Rowe, 'Making mathematics in an oral culture: Göttingen in the era of Klein and Hilbert', *Science in Context*, 17 (1/2) (2004) 85-129 (p.96).
[21] LUSA, Young Papers, D140/6/34-46 (Göttingen correspondence, October (n.d.) 1893).

formal basis until 1908. One of the reasons for Germany's relative tardiness in providing higher education for women was that, with a well established system of state-controlled education, there was no tradition of private philanthropy to provide impetus for new initiatives. Private colleges did not prosper to the extent that they did in Britain and America.[22]

Debate concerning women's potential for higher education

Germany and Britain were alike however in respect of the war of words waged over women's capacities for higher education. In contrast to the mathematics faculty, other departments and the administrative authorities at Göttingen were strongly against the admission of women. Max Runge, Professor of Gynaecology, argued that women's physiology made them weak and incapable of academic study, and that their whole organism had reached a less advanced state of evolution. Göttingen's highest official was wholly against Klein's plans to recruit female doctoral candidates and accused him of proposing 'a notion worse than social democracy, which only seeks to abolish the difference in possessions. You want to abolish the difference between the sexes'.[23] In fact, that was the last thing that Klein wanted to do. He argued for English-style single sex colleges for women and believed that medicine, law and theology were inappropriate for the female mind to study. Unlike mathematics, these subjects could introduce women to unwholesome ideas, expose them to unseemly public display and take them into areas from which God had ordained they should be absent. Grace was particularly nervous of telling Felix Klein that she intended to undertake part-time medical studies at Göttingen, no doubt fearing his displeasure. Grace gained a Medical Students' Registration Certificate on October 25th 1900, having decided to embark on medical training as a 'fall back' career. (Grace completed her formal medical studies but, as mathematics came to dominate her life, did not continue to complete the final, hospital-based training.) Grace was accepted as a student by the medical faculty as a special case and it was made clear that only experienced married women would be considered, a viewpoint with which Grace strongly agreed. There had been a precedent which may have helped her case. Pathologist Johannes Orth at Göttingen had given

[22] James C. Albisetti, *Schooling German girls and women: Secondary and Higher Education in the Nineteenth Century* (Princeton: Princeton University Press, 1988), pp. 131-132.
[23] Karen Hunger Parshall and David E. Rowe, *The emergence of the American mathematical research community, 1876-1900: J.J. Sylvester, Felix Klein and E.H. Moore* (Providence RI: American Mathematical Society, 1991), p. 244.

written permission for Florence Dyer from Boston to study, thinking that she was a man. When Dyer arrived in 1895 he felt compelled to admit her even though Göttingen's medical faculty had not yet accepted female auditors. In fact, Göttingen was the last to let women matriculate as medical students when Prussia finally gave permission in 1909.

The idea that women could not produce high quality academic studies without relinquishing their femininity or health was a frequently-voiced opinion in Germany. Max Planck, Director of Theoretical Physics at Berlin University, warned against eroding natural sex difference. It could 'not be stressed enough that Nature herself assigned to women the role of mother and housewife ..... to ignore natural laws is to invite great damage which will in this case be inflicted upon coming generations'.[24] Planck was alluding to fears during the 1890s, paralleled in England, surrounding Germany's perceived declining birth rate and high number of infant mortalities. The finger of blame was pointed at women for threatening national well-being by neglecting their role as mothers or losing their capacity for child bearing through inappropriate (masculine) intellectual activity. That Grace was influenced by these arguments can be evidenced from her endorsement of Max Runge's pamphlets, and by her support for Galton's views on the need to encourage childbirth amongst the educated middle classes.[25] Not withstanding Grace's favourable accounts of her experiences at Göttingen University, there is evidence that there was some antagonism towards foreign women who were benefiting from an education unavailable to German women. Margaret Maltby, who studied alongside Grace for a mathematics doctorate at Göttingen, gave an address in 1896 in which she reported that 'Many German women, and men, too, feel strongly the injustice of an attempt on the part of foreign women to avail themselves of certain university courses merely for the purpose of general culture'. She went on to argue that far more than just an individual woman's wishes needed to be considered: 'Let her admission come about in a way to command the respect of professors and students'.[26] This concern is one of the reasons why Felix Klein was so adamant that he would only accept

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[24] Ibid., pp. 123-4. However Planck could make exceptions: he eventually permitted physicist Lise Meitner to attend his lectures at Berlin in the early 1900s 'on a trial basis and always revocably ...... (but) .... I must hold fast to the idea that such a case must always be considered as exception, and in particular that it would be a great mistake to establish special institutions to induce women into academic study, at least not into pure scientific research. Amazons are abnormal, even in intellectual fields.' See Ruth Lewin Sime, *Lise Meitner: A Life in Physics* (California: University of California Press, 1996), pp. 25-26.

[25] UCL, Galton Papers, 344/2 (Grace to Galton, May 29 1909).

[26] Albisetti, pp. 234-5.

women students if they were proven 'capable of contributing'. Grace was quick to endorse this standpoint and stress that she did not want 'the universities to become the happy hunting ground of the mere knowledge desirer'.[27]

Felix Klein had been thwarted in an attempt to have another female mathematician admitted to his department in 1891 and the admission of Grace and her two female colleagues may have been a first victory for him in a long-running battle. American Christine Ladd-Franklin had completed all the requirements for a doctorate at Johns Hopkins University only to be denied her degree because of her sex. She had travelled to Göttingen with her husband, who was taking a sabbatical from Johns Hopkins, hoping to participate in university courses alongside him. When she was refused, Klein took up her case and argued for her to be accepted as a regularly-matriculated student. Klein was defeated in this and Ladd-Franklin was permitted entry as an 'auditor' only without student status.[28] Klein's later initiatives in gaining access for women were taken up quickly and enthusiastically by what became a network of supportive and generous women mathematicians.[29] When May Winston joined Grace at Göttingen, it was with the financial support of Ladd-Franklin who contributed $500 towards her costs after being made aware of Winston's financial worries by Charlotte Angas Scott. Angas Scott also sent Isabel Maddison, Grace's close friend and fellow student at Girton, to spend a year with Felix Klein on a Bryn Mawr scholarship between 1894-5. Towards the end of the century women were a regular, if small, contingent in Felix Klein's lectures and those of the other mathematics professors. Klein was not disappointed by his 'experiment': he wrote of Grace and her two American colleagues:

> We have had the most positive experiences: our three women are not only exceptionally diligent and conscientious, but their accomplishments are in no way inferior to those of our best students; indeed, to some extent they serve as a model for them.[30]

Both Grace and Maltby were aware of the added responsibility that they bore for all women and were keen to use their opportunities to more than

[27] LUSA, Young Papers, D140/8/1-321 (Göttingen correspondence, November (n.d.) 1893).
[28] Parshall and Rowe, p. 240.
[29] Felix Klein and David Hilbert continued to support female mathematicians. When Emmy Noether, who contributed mathematical foundations to Einstein's theory of relativity, came to Göttingen between the wars, both professors strived, without success, to have her join the staff. Noether was forced to work in defiance of the university authorities, teaching what were 'nominally' Hilbert's lectures, without pay or position. See Lynn M. Osen, *Women in Mathematics* (Cambridge, MA: MIT Press, 1974), p. 151.
[30] Parshall and Rowe, p. 244.

just personal advantage. This responsibility was one of the reasons why Grace resumed publication under her own name alone after her husband had finally gained a reputation and a professorship.

Motherhood, Eugenics, Nietzsche and Mathematics

A milestone in Grace's journey from a young woman who intended 'to lead a different life' to one who subscribed, in theory at least, to Victorian ideas of female service, was her writing of a private book for girls and their guardians entitled 'Mother Nature's Girl'. Here Grace argues that the first duty of a girl was to make her body a fit one for her to perform her duties as wife and mother - arduous duties which were no less valuable to the State than those of a soldier. The first duty of a boy was to serve his country.[31] Although Grace came to embrace ideals of 'the eternal motherly' in her writings, she did not pursue them in her daily life. Her unmarried sisters-in-law carried out the 'mothering' of her children, aided by a succession of hired 'girls', while she devoted her time to mathematics. This division between theory and practice is testimony to the conflicting influences that Grace was attempting to manage. On the one hand she loved mathematics and felt obliged to contribute something meaningful to it, on the other she acquiesced to the importance of duty to husband and family. Grace's views on motherhood complemented a growing interest in the emerging eugenic movement first articulated while she was a student at Girton. Her mother had been an admirer of Francis Galton and had contributed family data to him when he was collecting family statistics in the mid 1880s. Earlier, in 1865, Galton had published 'Hereditary Talent and Character' in which he had attempted to prove the heritability of intelligence on the basis of family pedigree data.[32] Galton defined eugenics as 'the science which deals with all influences that improve the inborn qualities of a race; also with those that develop them to the best advantage'.[33] He gave precedence to the former over environmental factors and his 1889 book, *Natural Inheritance* (a successor to *Hereditary Genius* which had been published twenty years earlier) represented the final formulation of his views on heredity and regression. In 1909 Grace resumed the family's contact with Galton by writing to him to express an interest in joining his new society. Galton had just had a paper of his printed in full in the

[31] LUSA, Young Papers, D140/12/22. This remained unpublished.
[32] See John C. Waller, 'Becoming a Darwinian: the micro-politics of Sir Francis Galton's scientific career 1859-65, *Annals of Science*, 61 (2) (2004), 141-163.
[33] D.W. Forrest, *Francis Galton: The life and work of a Victorian genius* (London: Elek, 1974), p. 256.

Westminster Gazette, in which he drew attention to the new Eugenics Education Society, and this probably prompted Grace's renewed interest. In her letter Grace wrote that it was 'evident that the aims you advocate are precisely those that my husband and I have at heart and which we have been both practically and theoretically working to advance'. This was a reference to her six children whom she described as especially talented and 'a test case for many questions in heredity, both for mental and for physical peculiarities'.[34]

According to Greta Jones, the Eugenics Education Society (which was just one element of a broader, more complex eugenics movement) was an essentially middle-class group which tended to emphasise intellectual achievement and the inherited aristocracy of talent.[35] This description is an apt one of Grace and her concerns. Implicit in eugenics was the belief that the most important human characteristic was mental ability and that this was inherited through the generations. This idea, which implied a *natural* (not social) elite of gifted intellects, sat well with a pure, highly abstract mathematics which was believed to be the creation of the 'greatest minds'.[36] One historian of mathematics has stated that one of the 'definitive contributions' of nineteenth-century developments in pure mathematics was 'the recognition that mathematics is not a natural science, but an intellectual creation of men'.[37] In Germany as in England, eugenic ideas were beginning to gain a foothold as the country went through similar processes of industrialisation, declining birth rate and social change. Concerns for racial hygiene had found expression in a movement active since the 1890s and a Racial Hygiene Society had been established in Berlin in 1905. As well as concerns over diseases and social problems such as alcoholism, women giving birth to fewer than two children were also targeted as exhibiting deviant behaviour.[38]

Grace's admiration for Galton was complemented by her growing espousal of the language and ideas of German thinker Friedrich Nietzsche, quotations from whose work appear in Grace's personal notebooks. Although Nietzsche's last book had been published in 1889, it

[34] UCL, Galton Papers, 344/2 (Grace to Galton, May 9 1909).
[35] Greta Jones, *Social Hygiene in twentieth-century Britain* (London: Croom Helm, 1986), especially pp. 18-19.
[36] '...the eugenic theory of society, as elaborated by Galton, is a way of reading the structure of social classes on to nature' : Donald A. Mackenzie, *Statistics in Britain 1865-1930: The social construction of scientific knowledge* (Edinburgh: Edinburgh University Press, 1981), p. 18.
[37] Carl B. Boyer *A history of mathematics* (New York: Wiley, 1968), p. 649.
[38] Paul Weindling, *Health, race and German politics between national unification and Nazism, 1870-1945* (Cambridge: Cambridge University Press, 1989), p. 9.

was not until the mid 1890s to early 1900s that he became a figure of major influence whose ideas were discussed and pressed into service by those involved in intellectual, social and political activities in Germany. Although Nietzsche's work can be obscure and open to interpretation, his principal ideas centre on contempt for Christian 'slave morality' (with its compassion for the weak) and a glorification of the 'superman' who has the will to dominate and is above ordinary morality. This elite *Übermensch* is part of a 'master class' whom the rest of humanity are there to serve. The *Übermensch* is always characterised as male; for Nietzsche, women lacked the 'will to power' that superior human beings possess and so were destined for servitude: 'Women want to serve and find their happiness in this'.[39] The term 'eternal-womanly' is used by him to emphasise woman's moral duty towards man as helpmeet.[40] Nietzsche constantly reiterates that there are higher human beings who are more valuable than the mass and for whose sake the mass exists and must be sacrificed. These sentiments are reflected exactly in Grace's poem to her son who was killed in 1917 during World War One. Using Nietzschean terminology, she calls Frankie 'Superman', 'the Great Exception', the 'Arab steed' in the presence of 'carthorses'. Adding Galton's ideas to Nietzsche's philosophy, Grace argues that the 'Superman' can be identified though the use of the 'new intellectual tests'. The poem concludes:

> We must help the Sprit to power,
> And not leave it to mere numbers
> for everywhere it is always the stupid
> who are in the majority all the time.....
> And rather let the stupid suffer
> than the clever ones be stifled by him![41]

Of course, this poem was written in the despair of death, but ideas about the superiority of the male intellect were an ever increasing preoccupation of Grace's since her days at Girton. According to Grace's notes at least, Young (who in her autobiographical jottings she calls, with obvious connotations, 'Mr King') had proclaimed himself 'greater

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[39] Quoted in Ellen Kennedy, 'Nietzsche: Women as Untermensch', in *Women in Western Political Philosophy: Kant to Nietzsche*, ed. by Ellen Kennedy and Susan Mendus (Brighton: Wheatsheaf, 1987), pp. 179-201 (p.185).
[40] Despite this misogyny, in Germany and England some feminists subverted Nietzsche's stricture to follow instinct and found an egalitarianism in his call to 'be what you are': Hinton R. Thomas *Nietzsche in German politics and society: 1890-1918* (Manchester: Manchester University Press, 1983), pp. 80-88; Lucy Delap, 'The Superwoman: Theories of gender and genius in Edwardian Britain', *Historical Journal*, 47 (1) (2004), 101-126.
[41] LUSA, Tanner Papers, D599/16 (Grace's notes).

than the world around him', citing this as the reason why his abilities went unrecognised.[42] In the early days of their marriage at least, Grace was preoccupied with showing to the world that her husband was no ordinary man, a preoccupation made more urgent by her family's dislike of him and his failure to acquire a suitable post. She compares him to Socrates and Browning in her letters and writes that she finds 'my greatest comfort and joy in reading about really great men'.[43] Grace's glorification of the male mind can only have been confirmed by her experiences in Göttingen.

Mathematics, 'great minds' and masculinity

Despite the sympathy to women students shown by the mathematics department, Göttingen's masculine rituals, and the style of mathematics pursued there, were all informed by a glorification of the single, male intellect. Unlike mathematics at Cambridge University, which by the 1880s was just beginning to catch up with Continental developments in analysis, Göttingen privileged research and promoted creative mathematics. The University's celebrated professors - Felix Klein, David Hilbert, Hermann Minkowski and others - established schools around them which attracted 'disciples' from all over the world. In this, Göttingen became a model for later Cambridge and the new American universities. Within this structure, admiration of individual mathematical minds could easily turn into myth-creating glorification. Contemporary accounts emphasise the awe with which these individuals were viewed by the students, an interpretation unthinkingly repeated by later accounts that present these 'mathematical heroes' within the standard narrative of eccentric genius.[44] Klein is described variously as 'regal', 'kingly', 'Olympian' and even the 'divine Felix'.[45] After their first meeting, Grace gushed that he was born to lead and that 'Cambridge has nothing to compare with him, both as mathematician and as man'.[46] Apocryphal stories surrounded him such as if dining at Klein's house a student was sometimes so awed by his host that he stood up when he was asked a question.[47] Hilbert was also the subject of mythologizing anecdotes.

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[42] LUSA, Young Papers, D140/12/67.

[43] Ibid., D140/6/318a.

[44] For example, Reid, *Hilbert;* and Herbert Meschkowski, *Ways of thought of great mathematicians: An approach to the history of mathematics*, trans. by John Dyer-Bennet (San Francisco: Holden Day, 1964).

[45] Reid, p. 46.

[46] LUSA, Young Papers, D140/8/1-321 (Göttingen correspondence, October (n.d.) 1893).

[47] Reid, p. 89.

These centred not only on the abstraction and difficulty of his mathematics, but on his penchant for shabby clothes, inveterate womanising, and his infamous mathematical walks during which students followed him around Göttingen while engaging in mathematical brain storming. The celebrity of these 'great men' reached its apotheosis in 1912 when a series of postcard portraits of Göttingen mathematicians went on sale in the town (figure 2.2).

Mathematics dominated Göttingen and the students, too, enjoyed special status. One journalist recalled the lordly young men who wore 'their caps visored in the bright colours of duelling fraternities, their faces usually swathed in bandages.' They left behind them 'a nauseating odour of iodoform which penetrates everywhere in Göttingen'.[48] In common with other German universities, duelling was a tradition at Göttingen. As duelling scars were regarded as badges of courage and honour, cuts on the face were left open to heal so that they would leave telltale marks. Grace echoes this account of Göttingen's duelling culture, where students fought duels on a Saturday night before an audience, in her fictionalised autobiographical writings. Here she has the daughter of a 'delightfully patriarchal' professor's family remark that

> .... I never look at a student who has not yet got *Schnitte* (cuts on face). If you look at the students on the Weender Strasse (Straße), when between 12 and 1 they parade up and down, especially on a Sunday, you will see them all bandaged up and the whole place smells of carbolic![49]

This account may have been modelled on Felix Klein's family with whom Grace became firm friends. By the 1890s duelling was frowned on by the authorities yet it was still a favoured activity amongst undergraduates; it was even endorsed by the Emperor in a speech at Bonn University in 1891.[50] Duelling can be interpreted as the German equivalent to the bodily training and exercise that accompanied preparation for the competitive mathematics tripos at Cambridge. The structure of the duel - one man's physical strength and cunning pitted against another's - was the model for interpreting the activity engaged in by mathematicians. In Göttingen, individual minds were seen as the

[48] Ibid., p. 102.
[49] LUSA, Tanner papers, D599/16.
[50] Social prescriptions did not allow women to duel as duelling was intimately connected to masculinity. Duelling was also popular in France from around 1860 to World War One where it was used as a strategy to retain certain cultural and political arenas as wholly male. See Robert A. Nye, *Masculinity and male codes of honor in modern France* (Oxford: Oxford University Press, 1999), pp. 172-215. (Thanks to Fiona Reid, University of Glamorgan, for this point.)

producers of new mathematical knowledge. The professors were engaged in 'intellectual duels', using their brilliantly-penetrating minds in place of swords, and the victors were those who published first and received the credit, often attaching their name to a theorem that would be remembered by generations of mathematicians to come.[51] The professors bore their scars too. Felix Klein suffered a mental breakdown said to be caused by rivalry with Henri Poincaré who was developing similar ideas at the same time.

The structure of the Göttingen mathematics department reflected the idea of competition too. Access to seminars was restricted to top students who had 'won their spurs' in what has been called a 'highly competitive and unashamedly elitist approach to mathematical education'.[52] (Grace wrote of her excitement and nervousness at being required to give a paper in front of the mathematics professors at one of Klein's seminars.) Severe competition was also a feature of meetings of the Göttingen Mathematical Society where 'the atmosphere (was) anything but relaxed'.[53] But for a woman to be a competitor, especially alongside men, was problematic. Men were prepared for competition, but ideals of femininity as complement and helpmeet to man dictated that women (middle-class women at least) should remain in the private sphere and not engage in public debate with men. Although these ideals were not rigid but adapting and evolving as women negotiated demands for higher education and the vote around them, Grace was not alone in adhering (in theory at least) to such codes of female behaviour. Much opposition from men and women to the suffrage movement pivoted on the unseemliness of women speaking on public platforms and acting in an altogether 'unladylike' manner. Grace expressed similar sentiments when she explained her anti-suffrage stance on a dislike of 'the argumentum ad hominem' of the suffragists which 'degraded' the whole subject.[54] Grace's husband engaged in a bad-tempered dispute (or duel) over priority with Schönflies which was played out in mathematics journals during the mid 1900s;[55] it would have been difficult for Grace, as a woman, to defend her position so robustly and acrimoniously as her husband was able to

[51] In a recent article, David E. Rowe has highlighted the social aspects of the production and teaching of mathematics at Göttingen; despite this, mathematicians gained great, individual reputations and this process may have been encouraged by the collective, oral ('shared') nature of mathematical research which created an environment within which individual talent and creativity could be displayed - and admired. Rowe, 'Making mathematics in an oral culture'.
[52] Parshall and Rowe, p. 190.
[53] Rowe, 'Making mathematics in an oral culture', p. 97.
[54] LUSA, Young Papers, D140/12/22 (Grace's autobiographical notes).
[55] For example W.H. Young, 'Reply', *Messenger of Mathematics,* 42 (1913), 113.

do. Grace's decision to allow her husband to compete in the mathematical world, with her 'back room' support, can be seen as a compromise that (in part) reconciled her mathematical ambitions with this sense of feminine propriety.

Göttingen's standing in the mathematical world at the turn of the nineteenth century was epitomised in its reputation as 'the Shrine of Pure Thought'.[56] At a time when a power struggle was being played out over the foundations of mathematics, Göttingen-style abstraction was beginning a transformation of mathematics which would revolutionise the discipline. By the later 1880s Cambridge, for so long a centre of mathematical excellence, was seen by some mathematicians as merely a 'training ground for passing exams' rather than a 'real university' engaged in research and producing creative mathematics.[57] This was one of the reasons why Grace had decided to travel to Germany. For one later Cambridge mathematical scholar, Grace's work at Göttingen had 'an enormous influence on the development of Cambridge mathematics'. Grace had introduced her friend Ernest Hobson to these new ideas and he went on to disseminate them at Cambridge.[58] Grace and her husband were at the forefront of the new mathematical analysis, most of their work being developments of Georg Cantor's theory of sets. Felix Klein made a habit of recommending particular areas that he felt were ripe for development and that his students could take further; this was the subject that he had recommended to Grace and, through her, to her husband. Cantor's work used powerful ideas, such as irrational numbers, complex numbers and differing powers of infinity, which enabled equations to be solved and mathematics to progress. It had opened up entirely new areas for mathematicians to work in, almost an early twentieth century job creation scheme. This is part of what David Hilbert was implying when, in response to criticism that these concepts were 'unreal' and therefore should not be a part of mathematics, he said with passion that mathematicians must not allow themselves to be 'thrown out of paradise'.

Although this new analysis had applications to physics - especially to new areas such as electrical wave theory and the calculation of probabilities which call for numbers beyond the natural sequence 1, 2, 3 etc. - at the research level it was far removed from worldly problems. Exponents of this new mathematics believed that existing methods had

[56] Reid, p. 92.
[57] Parshall and Rowe, p. 294.
[58] Mary L. Cartwright, 'Grace Chisholm Young', *Girton Review*, (Spring Term, 1944) 17-19 (p. 19).

come to a dead end. It was as if they were using a ruler but the thing that they needed to measure went not along the ruler but behind it, above and below it, and between its markings. A pair of variables represents a point in the plane and a triple represents a point in three dimensional space, but as the number of variables the analysts worked with increased so they found it necessary to posit spaces of a higher dimension. In 1905 David Hilbert produced his famous theory of infinitely many variables known as 'Hilbert Space Theory'. Grace and William Young presented their 1906 book, *The Theory of Sets of Points*, as 'the first attempt at a systematic exposition' of this new analysis and an 'attempt to further the frontier of existing knowledge'.[59] Opponents of this new analysis, not least in Cambridge, objected that the concepts it introduced (such as multidimensional space and many infinities, some greater than each other) were unreal, even occult. One of Germany's leading mathematicians, Leopold Kronecker, fought unsuccessfully against Cantor's work being published. Kronecker objected strongly that, with this new type of mathematics, the idea of mathematical truth involving some kind of correspondence to the real world was entirely jettisoned. Instead, truth lay in internal coherence and absence of contradiction; assumptions could be based on anything (not just observable facts) and they usually emerged from the creative minds of individual mathematicians. No wonder that these brilliant minds, seemingly pulling mathematical ideas out of nowhere, were revered and mythologized.

Pure mathematics, mathematical physics and engineering

The flight of pure mathematics into abstraction, and the glorification of the intellects that produced it, can be seen as a response to the growth in status and popularity of mathematical physics and engineering. In Germany, as in England, there was a growing opposition between pure and more practical mathematics, the pure mathematicians becoming increasingly elitist as they produced mathematics that only a small group of experts could read, let alone understand. At the same time mathematical physicists and the new physical sciences were engaged in expanding their sphere of influence and producing technology that could be seen to be changing the world. As a result, the more practical sciences were becoming popular subjects at university, challenging the historic prestige attached to pure mathematics. In Germany, tensions between these two specializing disciplines led to a revolt amongst mathematical

[59] W.H.Young and Grace Chisholm Young, *The Theory of Sets of Points* (Cambridge: Cambridge University Press, 1906), Preface.

and engineering teachers who wanted to reform mathematical education to cater more specifically to practical needs. Where the new engineers were democratising their discipline with technical institutes to train large numbers, the pure mathematicians were shunning any reference to the 'real world' as a contamination and emphasising the ability of only special individuals to further mathematics. Grace constantly put forward the view that what was important was not the success or utility of mathematics but 'the change in the mental point of view of intellectuals'[60] Furthermore, it was 'not the usefulness of mathematics that constitutes its claim to be a form of expression for the beautiful' and any application to the real world was 'merely coincidental'.[61] Grace concludes by likening mathematics to Art, although arguing that mathematics is more difficult and more 'occult'. This emphasis on the transcendence of pure mathematics is echoed by Georg Cantor who maintained that his theory of sets belonged 'entirely to metaphysics'.[62] Eleanor Sidgwick betrays similar moral concerns when she states of mathematics that a subject not studied for its own sake, but because of its usefulness for something else, 'is almost degraded in the process'.[63] G.H. Hardy, one of the first mathematicians to take up the new analysis in England, argued that mathematics cannot be justified for its 'crude achievements', that 'Real' mathematics was 'almost wholly useless', and, furthermore, that this very remoteness from ordinary activities kept it 'gentle and clean'.[64] Hardy also likened mathematics to Art, adding that the mathematician's 'beautiful and harmonious patterns' are more permanent because they 'are made with ideas' and there can be 'no permanent place in the world for ugly mathematics'.[65]

This was a philosophy entirely compatible with Nietzschean and eugenic ideas about elite individuals and in keeping with the tradition of hero worship at Göttingen. According to Grace's husband, William Young, engineers and practical scientists were 'merely technical' - 'coolies', not 'thinkers'.[66] Pure mathematics was the preserve of a (male) aristocracy of talent and the inexact, utility-driven maths of the growing band of engineers and technicians was as anathema as the new movement for

[60] LUSA, Young Papers, D140/7/3 (Grace's notes).
[61] Ibid., D140/14/1
[62] Meschkowski, pp. 94-95.
[63] Ethel Sidgwick, *Mrs Henry Sidgwick: A memoir by her niece,* (London: Sidgwick and Jackson, 1938), p. 65.
[64] Hardy, *Apology,* pp. 119-121. Hardy (1877-1947) was an analyst and friend of the Youngs; he was a professor of mathematics at both Cambridge and Oxford Universities.
[65] Ibid., pp. 84-5.
[66] LUSA, Young Papers, D140/24 (Young's notes).

socialism. This view retained echoes of the ideals of a liberal education. This tradition, encapsulated in the learning of dead classical languages, was in part based on the idea that knowledge, when applied to material ends, was an impure subject unworthy of the attentions of the intellectual elite. It was also a view coloured by class: the engineers and practical scientists engaged in providing education and technology in England (who were the target of Young's remark) were acutely aware of the need to assert their 'professionalism' as a way to achieve parity with more established, less 'hands-on' disciplines, as will be illustrated in the succeeding chapter. Young's view also had antecedents in the idea that knowledge is judged by the impartiality of its producer; the notion of a paid intellect was a new one and being dependent on applications in the real world, paid or other wise, could threaten the disinterested status that a mathematician's (or scientist's) credibility was based on.[67] But the movement of engineers and mathematical physicists was a growing one and the pure mathematicians were forced to negotiate their position in relation to it. Although basing their subject's intellectual and moral authority on its unconnectedness to the 'real world', the pure mathematicians fought for a position of superiority over those to whom worldly concerns were central.

In Cynthia Cockburn's materialist view of history, the makers of tools, from the early days of hand-held implements to today's computers, achieved status and power from their skill. The making of tools was (and is) confined to men, as toolmakers acquire power and authority in as far as people are rendered dependent on them.[68] In a move that fits this analysis, in the decades surrounding 1900 pure mathematicians condescended to create tools for the more practical mathematicians. As Klein explained to an audience of engineers, 'Mathematics' business was to formulate the fundamentals'; from where hypotheses originated, or whether they were based on observable fact, remained of no consequence. Mathematics was 'not responsible if the consequences of deductions do not correspond with reality'.[69] Grace and her husband

[67] For an exposition of this tradition see Shapin and Schaffer.
[68] Cynthia Cockburn, 'Technology, Production and Power', in *Inventing Women: Science, technology and gender*, ed. by Gill Kirkup and Laurie Smith Keller (Milton Keynes: Open University Press, 1992), pp. 196-211 (p.199).
[69] Lewis Pyenson, *Neohumanism and the persistence of pure mathematics in Wilhelmian Germany* (Philadelphia: American Philosophical Society, 1983), p. 54. Unsurprisingly, the engineers were unimpressed with Klein's comments and objected that theoreticians did not understand technical education. Despite this, it should be noted that Felix Klein sought to lessen the gap between pure and practical mathematics and initiated a movement for technical education at Göttingen. See Rowe, 'Klein, Hilbert and the Göttingen mathematical tradition', pp. 202-4.

introduced their book on analysis with a prediction that 'the near future will see a marked influence exerted by our theory on the language and conceptions of Applied Mathematics and Physics'.[70] This sentiment is echoed by Grace when she asserts that 'In the Dark Ages Theology was the Queen of Science. In the time to come she will yield her place to Mathematics of the purest and most abstract kind'.[71] The intrinsic superiority felt by the pure mathematicians is summed up by a contemporary anecdote that David Hilbert maintained that he had taught himself physics because 'Physics is too hard for physicists'.[72] Similar sentiments were expressed by G.H. Hardy when he wrote that applied mathematics 'is dull and for dull intellects'.[73]

Genius, gender and mathematics

It is not coincidental that both Grace and G.H. Hardy liken the pure mathematician to the artist. The romantic idea of genius had particular applications to Art. Although romantic philosophy had its roots at the beginning of the nineteenth century, as a reaction to an eighteenth-century rationalism that pictured man as 'an analytical machine, reducing complex phenomena to simple principles',[74] Victorian thinkers raised the ideal of the male genius to 'cult' status'.[75] Here the genius was born with talent - endowed by Nature with a rare gift as opposed to having learned or acquired a skill. The surrounding narrative presented this exceptional individual (artist, poet, mathematician or composer) as an isolated figure who used his creativity by force of spirit alone. This was a potent scenario in Germany in particular, drawing on a tradition of German idealism through Kant, Fichte, Hegel and Nietzsche, which stood in contrast to British inductive pragmatism. The latter, through the work of philosophers such as John Locke and David Hume, privileged empiricism, used inductive reasoning, and argued that all knowledge was derived from experience. German idealism, whose 'golden age' is generally held to be the 1770s to 1840s, had connections with

[70] W.H. and Grace Chisholm Young, preface.
[71] LUSA, Young Papers, D140/12/1-12 (Grace's notes). The term 'Queen of the Sciences' was a common characterisation which had been used since before the seventeenth century. See Schiebinger, pp.119-159 (p. 146).
[72] Young, *Mathematicians and their Times*, p. 246.
[73] Hardy, *Apology*, p. 135.
[74] John V. Pickstone, *Ways of Knowing: A new history of science, technology and medicine*, (Manchester: Manchester University Press, 2000), p. 56.
[75] See Susan P. Casteras, 'The cult of the male genius in Victorian painting', in *Rewriting the Victorians: Theory, history and the politics of gender*, ed. by Linda M. Shires (New York: Routledge, 1992), pp. 116-146.

Romanticism and was concerned with notions of 'pure thought'. Abstraction and 'purity', which was both the process and the product of the new mathematics, was a counterpart to the pure spirit which was held to work through the genius as Nature used him as its instrument. No wonder pure mathematicians were concerned with the development of individual minds and not with the bodily world. This dualism of mind and body, which rejects the world as corrupt, can be traced back to Descartes. At the end of the nineteenth century, this rejection can also be seen as a reaction to Darwin's materialist placing of man in the world alongside the animals, and a part of what is often called the 'crisis of the intelligentsia'. For example, Hardy's privileging of the 'pure' and notions of genius can be interpreted as an attempt to retain some idea of transcendence after he had lost his faith and become an 'ordinary educated unbeliever'.[76] The work of genius transcended normal confines and the more abstract a piece of mathematics, the more moral credibility it possessed. Genius had no truck with the bodily, which is one of the reasons why it was argued that women, rooted in the material world of reproduction, cannot possess it.

Although attempts were made by some feminists, in Germany and in England, to claim genius for the female sex, it remained a concept with strong masculine connotations and attempts to challenge this male exclusivity ultimately failed. Christine Battersby has written a comprehensive study of the history of gender and genius, tracing the concept from its prehistoric roots and demonstrating its connection with male sexuality. Battersby describes how 'genius' and 'woman' became conflicted ideas towards the end of the eighteenth century. At that time, a reaction against Enlightenment 'reason' resulted in a new discourse of creativity (centring on emotion, sensitivity and 'feeling') and this was then 'mapped-on' to existing ideas about masculine virility:

> This rhetoric praised 'feminine' qualities in male creators but claimed that females could not - should not - create.... The psychology of a woman was used as a foil to genius: to show what merely apes genius. Biological femaleness mimics the psychological femininity of the true genius. Romanticism, which started out by opening a window of opportunity for creative women, developed a phraseology of cultural apartheid.... The genius was a male - full of 'virile' energy - who *transcended* his biology: if the male genius was 'feminine' this merely proved his

[76] Hardy described himself as such in a 1942 letter to Grace Chisholm Young: LUSA, Young Papers, D140/9/64.

cultural superiority. Creativity was displaced *male* procreativity: male sexuality made sublime.[77]

This gendering of genius continued and, around 1900, the idea of female genius was marginalized in the influential works of Francis Galton and Havelock Ellis. Galton claimed that genius was inherited down the male line, adding that, on the rare occasion that women did possess genius, they would become so masculinised that they would be unmarriageable and so would be unable to pass on their ability. For Ellis, male genius was closely linked to men's sexual energy or 'vital force' and exhibited in intellectual and creative spheres; women's 'vital force' was used up in reproductive duties, so any feminine genius was manifested through 'love'.[78] The message was clear: the best a woman could hope for was to give birth to genius, not to become one herself.

Control of bodily impulses and sexual energy as a condition of authentic manliness has been identified as another key notion at the end of the nineteenth century. At this time, chastity and men's literature presented a struggle between 'mind' and 'body' and 'reason' and 'passion' as a key part of male experience. A distinction was made between 'manly' and 'male'; a man achieved manly status through self-mastery of his body and his sexual impulses.[79] (It was this kind of thinking that led to the rigorous physical training that accompanied competition in the Cambridge mathematics tripos.) In this way, male elites conceptualised masculinity as rational, thereby constructing femininity, by contrast, as emotional. The Göttingen analysts, concerned as they were with pure thought, were operating within both the narratives of disembodied genius and of manliness. It is notions such as these that underpin Grace's advice to women (specifically her daughter) thinking of entering university: 'The sensual life of a man, once awakened, eats up his powers' she warns, therefore 'it should not begin until the training of his career is over'. Furthermore, inflammatory women in academia could 'cause infinite harm to her comrades, sapping their strength and ruining their prospects. She herself is the sufferer, she herself who, whatever her personal ambitions, really longs for a superior male mind'.[80] It is significant that Grace used the terminology 'male mind' and not 'man'. Engineering was comprised of men concerned with the material and bodily; pure

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[77] Christine Battersby, *Gender and Genius: Towards a feminist aesthetics* (London: The Woman's Press, 1994), pp. 4-5.
[78] Delap, 'The Superwoman', p. 103.
[79] Ed. Cohen, *Talk on the Wilde side: Toward a genealogy of discourse on male sexualities* (New York: Routledge, 1993), p.32.
[80] LUSA, Young Papers, D140/14/6 (Grace's notes for her daughter, 1920).

mathematicians were 'superior', concerned with only the abstract and the mind. Furthermore, great mathematicians must be enabled to use their creativity and virility for mathematics, not tempted to dissipate their powers of genius in early relations with women.

For the pioneers who had brought an earlier version of continental analytics to Cambridge in the early nineteenth century, genius was a redundant concept. As outlined in chapter one, Babbage and Herschel rejected established authority in favour of learned technique and characterised their mathematics as a way to modernise and democratise the process of thought.[81] The new analysis at the rise of the twentieth century was very different. The earlier mathematicians had wanted to get rid of the subject and concentrate on objectivity. For Grace and her peers, the subject and the quality of his individual mind was all. The earlier analysts wanted to apply their calculations to the world; the new analysts judged their success by how far removed from the world they could make their mathematics. Old style analytics was a technique that the rising middle classes could learn and use as a weapon in their assault on aristocratic learning and privilege; new style analysis was an activity for a gifted elite. Both Grace and the Cambridge reformers criticised the mathematics tripos for its function as a treadmill for technique and quantity at the expense of creativity; like Whewell before them, they imported an ideology of romanticism and genius to privilege pure mathematics and the mathematicians who produced it. David Bloor has argued compellingly that even deductive, formal systems of knowledge are socially produced as their underlying premises, principles and assumptions are subject to negotiation and social acceptance.[82] New ideas deriving from Cantor's theory of sets, notions such as multidimensional space, many infinities and irrational numbers were controversial at first and split the mathematical community. There was no certainty that mathematicians would not be thrown out of Hilbert's 'paradise'. However, Grace and her peers were amenable to a system of mathematics which was unsullied by the 'real world', rested its moral credibility on abstraction, referred back to a tradition of neohumanist ideas, and preserved the status of an elite of intellectuals in the face of a challenge from the new, practical disciplines.

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[81] Ashworth, 'Memory, efficiency and symbolic analysis', pp. 646-649.
[82] Bloor, pp. 117-124.

The language of genius

By emphasising the genius of individual minds and basing their subject's intellectual and moral authority on its unconnectedness to the world, the pure mathematicians negotiated for a position of superiority over the physical mathematicians and engineers to whom worldly concerns were central. The abstraction and moral integrity of this style of mathematics was increasingly conveyed by the use of language that was highly feminised and romantic. Proofs were 'elegant'; theorems 'beautiful'. The aesthetics of theorems - simplicity, consistency, symmetry - became viewed as an element with which to judge their success. Bertrand Russell, who concerned himself with the logical philosophy underpinning analysis, believed that 'Mathematics, rightly viewed, possesses not only truth but supreme beauty..... sublimely pure'.[83] This feminised language distinguished pure mathematics from its uncouth partner, the applied, and helped women such as Grace to feel comfortable within the discipline. However, key to this language was its correspondence to the same androcentric idea of romantic genius described above; an idea that found its expression in feminised language, but its effect in excluding women.

By the end of the eighteenth century, the idea of genius was understood as intimately connected with the dynamism of male sexual energy; it has been described above how women experienced a tension with the terminology of genius due to its link with the creative force of male sexuality, and how men achieved 'manliness' via the mastering of their bodily, sexual impulses. Femininity, in opposition, was constructed as at core emotional, sensitive and intuitive, qualities which conflicted femininity with rationality, an attribute coded inherently male. However, one of the defining features of the genius was that he was sensitive, inspired and guided by instinct like a women, but also had the body and rationality of a man. Women were sensitive and emotional in order to (pro)create and be good mothers; men's creativity was realised though cultural production, as the long and tenacious history of the stereotype of the 'male genius' in art and culture illustrates. In this way, the genius was a 'third sex';[84] an embodied male able to access and use 'feminine' attributes in a way beyond any woman's reach. By using feminine language, pure mathematics reconciled abstract, 'masculine' rationality

[83] Bertrand Russell, 'The study of mathematics', in *Mysticism and Logic, and other essays* (London: Penguin, 1953) pp. 60-61 (p. 60).
[84] Battersby, p. 148.

with 'feminine' intuition and instinct, a dichotomy that resulted in genius. In Germany, this association was strengthened by a particular construction of elite masculinity that presented the ideal, 'whole man' as a combination of male and female ideals - someone 'who combines all of the qualities that are separated in the polarised gender model'.[85] It is this view that Grace may have been alluding to when she wrote of yearning for the support of 'the complete man'. But not content with being credited with genius, the great mathematicians at 'the Shrine of Pure Thought' were deified too. One student of 'the Divine Felix' maintained that even after he came to know him well, he still felt the distance between himself and Klein 'as between a mortal and a god'.[86] On her arrival in Göttingen, Grace quickly acquired similar terminology, remarking on 'epistles' that she had received from Klein and calling his rooms 'the sanctum'. The notion of God as a divine mathematician has had currency since the days of Pythagoras; for Margaret Wertheim this is just a short step away from the idea of mathematicians as divine, and the reason why women have been excluded from the 'priestly' practices of mathematics and physics.[87] Certainly, there were few models of female transcendence or genius in Western thought for Grace to negotiate an identity around. Instead, surrounded by prescriptions that served to limit female ambition and opportunity, overwhelmed by romantic notions of genius, and practising a pure mathematics that privileged the abstract male intellect, she decided to transfer her mathematical ambitions onto her husband.

Conclusion

When Grace attended a mathematical dinner held in honour of Felix Klein, her lone female presence on this elite occasion was explained by the fact that she was 'there as a mathematician, not as a woman'. The tension between these two terms was still acute enough to require amplification. In this world of pure mathematics, where the worth of a particular piece of mathematics was based not on its success or utility but on its beauty and internal consistency, and where what constituted a 'proof' was open to debate[88], it was essential to situate yourself as a mathematician of high ability and gain the trust of your audience that this was so. Grace found it increasingly awkward to characterise herself

[85] Martina Kessel, ' "The 'Whole Man": The longing for a masculine world in nineteenth-century Germany', *Gender and History*, 15 (1) (2003) 1-31 (p.2).
[86] Reid, p. 46.
[87] Wertheim, p. xv.
[88] For a discussion of the problematic nature of proof at this time see Jeremy J. Gray, 'Anxiety and abstraction in nineteenth-century mathematics', *Science in Context*, 17 (1/2) (2004) 23-47 (pp. 27-29).

as such, or to contest the undercurrents in the Göttingen mathematical community that made it difficult to see how she, as a woman, could – or should - aspire to the genius of male intellects such as Hilbert and Klein and become their peer. Overwhelmed by romantic notions of genius, and practising a pure mathematics that privileged the male intellect, she seemed to lose confidence. Grace continued to research mathematics, was in constant correspondence with leading mathematicians, and remained highly respected within the mathematical community. However, she severely compromised her personal ambitions and, instead, used her mathematical connections and skill to support her husband. The couple's collaborative practices will be explored in chapter four, suffice to say that Grace published only four papers under her name alone (including her PhD dissertation) up to 1915; she resumed only after 1914 when Young was finally awarded a professorship. (Grace's later work was influential in the field of differential calculus and one of her papers won the Cambridge Gamble Prize for Mathematics in 1915.) Despite this, Grace's exposure to the romantic culture and ideology of 'the shrine of pure thought' led her to question her identity as a mathematician and to elevate her husband (not herself) to the same level as the great Göttingen mathematicians whom she revered: a small and elite club that was open, she came to believe, only to men.

Figure 2.1.

The Mathematics Club of Göttingen, 1902
Left to right, front row: Abraham, Schilling, Hilbert, Klein, Schwarzschild, Mrs. Young, Diestel Zermelo; second row: Fanla, Hansen, C. Müller, Dawney, E. Schmidt, Yoshiye, Epsteen, Fleisher F. Bernstein; third row: Blumenthal, Hamel, H. Müller

From Constance Reid, *Hilbert* (London: Allen and Unwin, 1970), p. 228

Figure 2.2.

David Hilbert, 1912 — one of a group of portraits of professors which were sold as postcards in Göttingen

From Constance Reid, *Hilbert* (London: Allen and Unwin, 1970), p. 231

Chapter three

Professional or pedestal?
Hertha Ayrton, a woman among the engineers

In 1889, the Electrical Trades Union (ETU)[1] sought to symbolize its work and purpose with a new, specially-commissioned banner bearing the words 'Light and Liberty' (figure 3.1). This classically-inspired image invites a number of interpretations and allusions, each with gendered meanings. The banner is dominated by the central figure of a glorious 'angel of light', a female personification of both electricity and the union, who presides on a pedestal while spreading her wings above six male figures.[2] The latter, unlike the abstract 'angel', are representations of real, individual men made recognisable by being clothed in the identifiable garb and accoutrements of their differing trades. These workmen reach up to the female figure to acquire and master the wonderful power of electricity which they then control and fashion into technology, while the 'angel' simultaneously seems to protect them and offer up her fabulous, natural power.

In the final decades of the nineteenth century, as electricity and consumer culture developed hand-in-hand, electricity could be represented, not least by companies marketing their new electrical devices, as an almost magical, invisible force that could be conjured and used for a myriad of domestic, medical and other purposes. From the late 1880s electric lighting was increasingly replacing gas in the homes of the well-heeled middle and upper classes, while medical and other devices (such as the galvanic equipment that Grace Chisholm's invalid sister used to treat muscles wasted by polio) were promising the chance of a better, more comfortable life. In this context, the use of the female form in industrial images reflected an acknowledgement that women were users and consumers of new electrical technology, even if they were not

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[1] The Electrical Trades Union had been formed in 1868; after several mergers, it now exists as part of Amicus, the union of technical and manufacturing personnel.

[2] Although angels had been previously viewed as of the masculine gender, the Victorian period witnessed their being represented increasingly as female, as part of a general feminisation of Christianity; see Callum G. Brown, *The Death of Christian Britain: Understanding secularisation, 1800-2000* (London: Routledge, 2001), pp. 58-87. The ETU's use of an abstract female figure to represent electricity and their organisation adhered to longstanding traditions; see Marina Warner, *Monuments and Maidens: The allegory of the female form* (London: Weidenfeld and Nicolson, 1985).

engineers of it. But these feminine representations served a purpose beyond just the recruitment of women customers: 'The goddess archetype helped lend an aura of dignity, legitimacy, and stability to a world of rapid mechanization and technological change'.[3] The electricity industry, in particular, used classically-draped and posed 'electric eves' as emblems of the electric age.[4] These mythic figures, whose bodies were often transformed magically through the use of electricity, were used to decorate technological products, on technical literature, and as huge sculptures at exhibitions and trade fairs.[5] It is clear that the use of the classical feminine archetype on the ETU banner was designed to surround this young, working class union with an aura of moral worth; it also suggested status and professionalism. The ETU had been formed in 1868, after the Amalgamated Society of Engineers (formed 1852) had refused membership to electricians. The ETU's new banner affirmed its parity with the engineers and, in a society that traditionally privileged 'intellectual' over 'practical' work, represented the electrical trades as more than just 'working class' labour. Around the same time, the Institution of Electrical Engineers (IEE) had used a similar strategy to convey messages of moral integrity, and to inspire unity among the 'practical' and 'professional' men within its membership. On the centenary of his birth, the telegraphic and electrical engineers of the IEE invoked the figure of Michael Faraday as 'founding father' of their specialized profession, creating a mythology around him and using his image on their first institutional seal.[6]

Aims

While the new ETU image reflected metaphors of science that had long personified the world and her forces as female; it also acknowledged that the technical business of engineering this new force of electricity, and using it to bring important new benefits to the service of mankind, was a wholly male enterprise. Middle class woman such as Hertha Ayrton are subconsciously invited to identify with the 'goddess' figure (typically the only female representation within such images) rather than with the men who mediate her power. In this way, the banner reflects contemporary

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[3] Julie Wosk, *Women and the Machine: Representations from the spinning wheel to the electronic age* (Baltimore: Johns Hopkins Press, 2001), p. 17.

[4] Ibid., 'The Electric Eve', pp. 68-88. Wosk has traced such images of technology and women back to the mid eighteenth century.

[5] Ibid., pp. 18-19.

[6] Graeme Gooday, 'Faraday Reinvented: Moral imagery and institutional icons in Victorian electrical engineering', *History of Technology*, 15 (1993), 190-205.

society's expectations of women, and the 'decorative', passive roles considered appropriate for them to assume. The gendered messages conveyed by the ETU's new banner are indicative of the representations and experiences of Hertha as she attempted to participate as a peer, from the mid 1880s until her death in 1923, in the worlds of electrical engineering and experimental physics. By following Hertha from Girton College to the very different context of Finsbury Technical College and, later, the Central Institution in South Kensington, this chapter will explore the culture and practices of practical science to illustrate the difficulties, both conceptual and actual, presented at turn of century by a woman practising in a male scientific domain.

In the last chapter, a discussion of Grace's experiences at Göttingen served to illustrate how pure mathematics' flight to abstraction connected to its privileging of individual minds and ideas of elite intellect, and how both helped to create a gender bias that posed questions for women seeking to contribute on the same level as the most revered men. In contrast, in this chapter it will be suggested that in order to present themselves as modern and progressive, scientists at Finsbury and South Kensington emphasised action in the world and cultivated an active, masculine concept of service to legitimate their concerns. On one level, Hertha was welcomed into the technical community in accordance with its self promotion as a new and meritocratic movement in contrast to the elitist, theoretical erudition represented by Cambridge science and much of the Royal Society. On another, negotiating as it was for status and finance, this new technical, education and engineering initiative could not afford any hint of femininity to cloud its image as a producer of 'heroic' men who embodied a new kind of scientific citizenship, and whose skills were to be used for the good of society, country and Empire. As Hertha strived to create an identity as a professional scientist 'from the scientific, not the sex, point of view',[7] so sympathisers, observers and detractors sought to foreground her femininity.

Descriptions of Hertha's public lectures and experiments echo the ETU banner by using language which elides a woman in command of nature with woman *as* nature. In June 1899, the *Daily News* reported how she invoked 'astonishment' by bringing unpredictable forces to heel at a Royal Society Conversazione where she was 'in charge of the most dangerous-looking of all the exhibits – a fierce arc light enclosed in

[7] Sharp, *Hertha Ayrton*, p. 182 (Hertha's comments in an interview with the *Daily News*, July 16, 1919).

glass. Mrs Ayrton was not a bit afraid of it'.[8] With similar admiration for a wonder of scientific femininity, a distinguished electrical engineer used lyrical, rather than scientific, language to describe the 'beautiful experiments' on wave formation by which Hertha made herself 'mistress of sand ripples'.[9] In these descriptions Hertha is presented as an extraordinary individual far removed from the prosaic abilities and concerns of her more ordinary sisters. Unable to mould her into expectations of what a (male) engineer and scientist should be, and unwilling to accept her as no different from her male peers, commentators turned her instead into an iconic 'angel of science'. This kind of characterisation worked to Hertha's advantage while she was young and at the start of her career but, as will be discussed in chapter seven, it easily became inverted as she became an older widow with political as well as scientific ambitions. At Göttingen, ideas of abstract, male genius worked to keep gender hierarchies in place in the context of pure mathematics; at Finsbury College and the Central, it was the fusion of masculinity with a new kind of scientific citizenship that combined to keep Hertha and other female practitioners at the periphery of the engineering profession.

Women, technology and technical training

An important factor preventing women from participating fully in male-dominated technical areas has been their lesser access to training. Even when opportunities are open nominally to both sexes, the culture of the training and education environment, together with gender prescriptions of society at large, can combine to create a strong disincentive to technical women. When Hertha embarked on a course of evening classes at the new City and Guilds Technical Institute at Finsbury in 1884 she was one of just three women taking electrical and applied physics courses alongside 118 men.[10] Most women, although still small in number, preferred applied art and combined evening classes with occupations such as teacher, clerk or illustrator. Hertha's decision to study at Finsbury was a reflection of her discontent with the tutoring

[8] Ibid., p. 144. Hertha's experiments could be spectacular in the context of a lecture, as she explained in *Nature*, it was impossible for her to use an ordinary enclosed arc lamp as these used currents of up to only 8 amperes, 'whereas to test my theory it was necessary to employ currents up to 40 amperes. Accordingly, I constructed little electrical furnaces of different kinds...', Hertha Ayrton, 'The reason for the hissing of the electric arc', *Nature*, 60 (July 17, 1899) 302-305 (p.303).

[9] Institution of Electrical Engineers (IEE), Library and Archives, memoirs of A.P. Trotter, pp. 569-591. Trotter had been a president of the IEE.

[10] London Guildhall Library (LGL), Department of Manuscripts, Records of Finsbury College, 29,973 Hertha is listed as 'Sarah Marks'.

roles that she had undertaken since leaving Girton, and may have represented for her an opportunity to add expertise to inventive skills which had already resulted in patents for a 'mathematical, dividing and measuring instrument'.[11] This small device was manufactured by W. F. Stanley of Holborn and marketed as being useful to architects and engineers for such tasks as specifying 'treads and risers of stairs, joists, roof-timbers, girders, brick spaces ......'.[12] Although the fact that a woman had solved 'a problem that has often taxed the ingenuity of technical men' caught the eye of the press,[13] the design and manufacture of small mechanical instruments was not a novel activity for a woman. Women were active in a thriving scientific instrument trade, concentrated in the fringes of London, which offered bespoke and standard products and sought custom from institutions, laboratories, professional practices and individuals. Discounting the 'invisible' women who worked with male relatives in small businesses, women were registered in their own right as makers of drawing and mathematics instruments and producers of navigation and optical equipment.[14] Hertha may well have harboured ambitions to earn an independent living in this way, following the example of her late watch-maker father, a suspicion supported by her choosing to study at a college that was newly established to provide practical training that could be transferred to the workplace.

Finsbury Technical College had been conceived as part of a broader initiative to address the scarcity of structured technical training amidst fears that other countries, notably Germany and America, would outstrip England in commercial competitiveness. In 1879 a committee set up by the City and Guilds of London Institute had established evening classes in chemistry and physics in premises rented from a school. These classes were soon oversubscribed and facilities judged inadequate, so a new college was built at Finsbury in 1883 to provide a permanent home. Funded by the London livery companies, the College's emphasis was placed firmly on training for industry. As one of the first professors,

[11] Three patents were taken out during 1883 and 1884, the first in conjunction with her cousin Ansel Leo.
[12] Tattersall and McMurran, p. 94 (advertising for 'Marks' Patent Line Divider').
[13] Sharp, *Hertha Ayrton*, pp. 108-9 (from *Academy Magazine*).
[14] A.D. Morrison-Low, 'Women in the nineteenth-century scientific instrument trade', in *Gender and scientific enquiry, 1780-1945*, ed. by M. Benjamin (Oxford: Basil Blackwell, 1991), pp. 89-117. Within this tradition, one of most respected names was Janet Taylor (1804-1870) who produced navigational instruments, ran her own business and counted among her clients organisations such as the East India Company and the British Admiralty (John Croucher, 'The Remarkable Janet Taylor: first lady of navigation', lecture, National Maritime Museum, May 21st 2004).

John Perry, explained in an address to the Old Students' Association, Finsbury's training was 'peculiarly practical'. He stressed that although managers could be prejudiced against college-trained (as opposed to apprentice-trained) students, 'they would show them that Finsbury is a college of a different class, which can turn out men who are really worth their salt, who will have some sympathy with workmen, and who will not be afraid of dirty hands and hard work'.[15] Efforts were made to build connections with local industry so as to secure students and credibility; apprentices, journeymen and foremen who were employed during the day took evening classes, while individuals aged fourteen years and over attended sessions in the daytime. Electrical engineering was a speciality at Finsbury and other subjects included chemical and mechanical engineering, cabinet making, building trades and applied art; included on the timetable for the year that Hertha attended was an evening class on steam engines. After two years, or three in the case of evening students, a 'Technological Certificate' equivalent to passing certain of the Department of Science and Art's examinations was awarded to successful candidates.

The austere, factory-like architecture of Finsbury College reflected its role as a 'hands-on' servant of industry. Unplastered walls served to highlight its affinity with the workshop and there were no reception or committee rooms, library, refreshment or staff common room. In keeping with this masculine, industrial arrangement, the original plans had omitted any female toilet facilities - an oversight that had to be remedied hastily when a need was recognised.[16] This environment was far removed from the gentility of Girton College and the comfortable drawing rooms that Hertha had frequented as a private tutor. There was no room for overt femininity (or comfort) in a college designed to counter scepticism of engineers trained away from the workplace, or in one which aimed to prove that 'Finsbury men' were just as tough and willing to get their hands dirty as apprentice-trained technicians.[17] That

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[15] LGL, 21,986 (Prof. J. Perry, 'Address to Finsbury Technical College and Old Students' Association, 1888'). John Perry (1850-1920) taught Mechanics and Applied Mathematics at Finsbury, transferring to the Central Technical College in 1884. With William Edward Ayrton (Hertha's husband) he invented many electrical measuring instruments and worked on railway electrification and in other areas. Perry was elected to the Royal Society in 1885.

[16] W.H. Brock, 'Building England's first technical college: The laboratories of Finsbury Technical College, 1878-1926', in *The Development of the Laboratory: Essays on the place of experiment in industrial civilization'*, ed. by F.A.J.L. James (Basingstoke: Macmillan,1989), pp. 154-170 (p.166).

[17] Graeme Gooday has demonstrated the processes by which this new academic space became accepted by industry as a viable engineering training venue: Graeme J. N. Gooday, 'Teaching telegraphy and electrotechnics in the physics laboratory, William Ayrton and the creation of an

women might want to engage in such a manly, utilitarian activity was viewed with surprise, amusement and indulgence by *The Electrician* magazine which remarked that at Finsbury 'Women may study electrical science without risk of alarming anybody or of doing any harm to themselves'.[18] Hertha did so three times a week for a year, funding herself with the financial support of her Girton benefactor Barbara Bodichon. Student records show that Hertha's choice of 'electro-technics' was by far the most popular course attracting more than twice the number of any other. As the omission of a 'ladies' in the design of Finsbury College suggests, women were not seen as potential students in any number - after all, women were not admitted to most trades and Finsbury trained individuals for industry.

Hertha concluded her training at Finsbury in 1885; her name (Sarah Marks) appears among 115 men in the table of results for that session at an undistinguished place near the bottom. For her laboratory assessment Hertha had gained just seven marks, significantly less than the top mark of seventy eight.[19] Although experimentation was an important component of the Finsbury training and 'for every hour that a student spends at lecture, he spends several in the laboratory'[20], it seems that Hertha was one of a number who did not attend the full assessment or failed to deliver proper 'laboratory notes'. This poor performance is indicative of the problems faced by a rare woman among the many men in the crowded electro-technics laboratory at Finsbury. Here, many of the students would be partially familiar with the workshop apparatus of telegraphy or electric lighting from exposure to them in their 'day jobs', an advantage that Hertha did not possess. Furthermore, students worked in teams to pursue their experimental work and it would have been difficult for a relatively inexperienced woman - at thirty years of age, older than many of her fellow male students - to become 'one of a team'. (Hertha's age is another indication of the particular way that women accessed technical education, coming to it via other routes rather than following a direct path via school, apprenticeship or the workplace as did most of the men.) Electro-technology courses were over subscribed at Finsbury and Hertha may have experienced tension in competing with

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academic space for electrical engineering in Britain, 1873-1884', *History of Technology Journal*, 13 (1991), 73-111.

[18] Cambridge, Girton College Library and Archive (GCLA), unpublished MS by Joan Mason, 'Matilda Chaplin Ayrton (1846-1883), William Edward Ayrton (1847-1908) and Hertha Ayrton (1854-1923)', (1994), p. 6.

[19] LGL, 21,980 (Finsbury Park evening examination results).

[20] W. E. Ayrton, *Practical Electricity: A laboratory and lecture course* (London: Cassell, 1900), p. xii.

men for apparatus, space and a glimpse of the demonstrator in crowded and, at times, disorderly classes. Although matters were reported to have improved to an extent by 1884, the previous academic year a student had complained to *The Electrician* that Finsbury was 'little better than in a state of chaos' and that the chief demonstrator was 'principally occupied in taking tickets and names at the door'.[21] At this time at Girton, women were still required to be accompanied by chaperones to outside lectures and coaching sessions with male tutors (this requirement would persist, nominally at least, until the next century) and it is difficult to see how Hertha could have made best use of Finsbury's training, jostling with men for space and resources, *and* have adhered to middle-class codes of genteel, female propriety. It is not surprising that even Sharp, in her proselytising *Memoir* designed to illustrate a woman's capability in a 'man's world', pays scant attention to Hertha's experiences at Finsbury, concentrating instead on her courtship with her professor there, William Edward Ayrton (1847-1908) and the latter's feminist credentials.

A marriage of scientific equals?

One way for a student to cope with the masculine classroom dynamics at Finsbury would be to have the special, out of hours, attention of the teacher. After a brief courtship, Hertha and Ayrton were married in May 1885. By this time, Ayrton had already achieved a reputation in telegraphy, electrical engineering and technical education, and in 1881 had been elected a fellow of the Royal Society. After studying mathematics at University College London, Ayrton had worked in the physical laboratory of Sir William Thomson (Lord Kelvin) at Glasgow, before taking posts with the Indian Telegraph Company and Great Western Railway, all of which gave him strong industrial credentials. Ayrton had returned from heading up the Department of Natural Philosophy and Telegraphy at the Imperial Engineering College in Tokyo to take up his professorship at the City and Guilds Institute (1879) and Finsbury Technical College (1881). It has become almost orthodoxy in the history of women in the sciences to point out how women needed 'male mentors' to facilitate access, create opportunities and act as intermediaries with the male scientific establishment. Taking this a step further, there is within this trope a developing body of scholarship illustrating how marriage was a significant route into science for many women.[22] However, as will be illustrated here with the relationship of

[21] Gooday, 'Teaching telegraphy and electrotechnics', pp. 102-3.
[22] For example, the collection of essays in Pycior and others, eds., discussed in the introduction.

Hertha and Ayrton (and with that of Grace and Young in the succeeding chapter) the 'mentor' model can sometimes be a limiting tool with which to analyse women in science. It has become a stereotype which obscures as much as it reveals, hiding the complexity of women's negotiations within science and implying passivity and a lack of agency. Although there is no doubt that Ayrton was an advantage to Hertha - as she surmised on her engagement 'he is going to let me go on with my electrical work, and of course he can help me in it in every way'[23] - the advantage also flowed in the opposite direction. Hertha was an asset in Ayrton's bid to establish his modern, emancipated credentials as a progressive man of science, and their scientific collaborations reveal a carefully-planned public relations strategy designed to further both their reputations. In addition, most of the little scholarship on Hertha focuses on her researches on the electric arc, yet this was not an all-defining work and Hertha's experimental career continued for a full fifteen years after her husband's death.

There is little doubt that Hertha was a suitable consort for Ayrton. Together they were a feature of London scientific society; attending Friday evening lectures at the Royal Institution, hosting a luncheon party for Heinrich Hertz (who had travelled to England to receive a Royal Society medal), presiding over Finsbury College's annual 'old students' dinner', or attempting to discover the science behind the 'thought-reading' couple who were 'bewitching' London at the Alhambra Theatre.[24] Ayrton's first wife had died two years previously; she too had been an independent-minded individual and was one of the first English women to gain medical qualifications.[25] When Ayrton died in 1908, appreciations were unusual in that they gave almost as much attention to his views on sexual equality as they did to his scientific achievements. A funeral notice in the *Morning Post* recalled how 'Ayrton felt that science was of no sex, and that chivalry could not consist of opening the drawing room door for women and closing the doors of scientific society'. The obituary continued with a call to Ayrton's peers: 'If his fellow-workers in science wished to honour his memory they could not better do so than by following his inspiration in this regard'.[26] A few years earlier Hertha had

[23]Sharp, *Hertha Ayrton*, p. 114 (letter Hertha to her mother).

[24] UCL, Galton Papers, 196/9 (correspondence W.E. Ayrton to Galton, February 17 1907).

[25] Matilda Chaplin Ayrton was one of the 'Edinburgh Seven' with Sophia Jex-Blake. She travelled to Paris to study for a medical degree, gained a Certificate in Midwifery from the London Obstetric Society and, while Ayrton was working in Tokyo, introduced Western midwifery practices into Japan: GCLA, Mason MS.

[26] LGL, 21,868/10 ('Funeral Notice, W.E. Ayrton', *Morning Post*, November 13th, 1908).

been refused a fellowship of the Royal Society, on the grounds of her sex and married status; this comment may well have been directed to the fellows and members of council who had refused her entry. In similar vein, a letter to *The Times* noted Ayrton's 'affinity for intellectual womanhood' and made the point that, unlike some men of science, he did not absorb his wife's life and work into his own. 'On the contrary he exerted himself to have her career recognized as separate and individual. This was his real contribution to suffrage.'[27]

Ayrton's sympathy with the women's cause was shared by other of his engineering colleagues. John Perry twice nominated Hertha for a Royal Society medal (and wrote her statements of endorsement) and Thomas Mather collaborated with Hertha and was one of her most loyal supporters.[28] On Hertha's death, Maurice Solomon, editor of the *Central Gazette* (the college newspaper) recalled that Hertha had been an 'inspiration' to the students who had worked with her. Despite this, he continued, Hertha's sex had been 'a continual hindrance to her work' and she had had to withstand 'a constant struggle against prejudice and old-standing prohibitions ... which even in success had led too many to judge her achievements by the sex of the doer'.[29] This nominal support for equality of opportunity and the suffrage cause can be interpreted as part of the negotiations of this new, practical science and education initiative to secure credibility for its methods and aims. During Ayrton's lifetime, the suffrage campaign had remained fairly 'ladylike'; although the militant Women's Social and Political Union (WSPU) had been established in October 1903 (with Hertha as an early member) it was not until around 1910 that its militancy escalated. As a result, the suffrage movement split into militant and non-militant wings and, for professionals in the public eye, arguing the militants' cause became considerably more controversial. Despite this, especially in the 1900s, supporting equal rights for women was in keeping with the presentation of these professional men of science as the prototype of the modern, progressive citizen - a new vision that stood in opposition to the 'prejudice' and 'old-standing prohibitions' of the older tradition of

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[27] Israel Zangwill, 'Professor Ayrton', *The Times*, November 11, 1908, Letters to Editor, p. 15. Zangwill, the Jewish writer, was a son-in-law of William and Hertha Ayrton and a member of the Men's League for Women's Suffrage.

[28] Thomas Mather (1856-1937) had been William Ayrton's Chief Assistant at Finsbury and the Central, where he succeeded Ayrton as Professor. On Hertha's death he rushed to counter accusations, made by professor of chemistry Henry E. Armstrong, that Hertha had been unoriginal and dependent on her husband: Thomas Mather, 'Mrs Hertha Ayrton', *Nature*, 112 (December 29, 1923), 939.

[29] Maurice Soloman, 'Review of Evelyn Sharp's *Hertha Ayrton, 1854-1923: A Memoir*', *Central Gazette*, 23 (59) (1926), 70-72 (p. 72).

gentlemen of science. Tension between these two groups was played out on various levels including the nature of scientific education, the dangers of commercialism, and the place of women in science. In chapter seven it will be demonstrated how Hertha's nomination to the Royal Society was part of an ongoing battle between opposing factions within that learned organisation; here the focus will remain on the Central Institution where Hertha carried out her best-known investigations into the electric arc.

Central men, active masculinity and scientific citizenship

The Central Institution at South Kensington opened in 1884 with financial sponsorship from the City and Guilds of London. It was renamed the Central Technical College in 1893 and in 1907 became a constituent of the newly-formed Imperial College of the University of London. The Central catered for 'graduates' from Finsbury and other schools/universities (Ayrton was particularly gratified to have a Cambridge wrangler in his class of 1896) returners from industry and a growing number of overseas students, especially from Japan, India and Egypt. These individuals came to the Central to gain advanced technical and professional training and the College is generally seen as being a prototype for the later polytechnics. One historian has written that by 1881 English technical education was reaching its 'heroic stage'.[30] The gendered adjective 'heroic' is telling. Pure mathematicians and other men engaged in inactive intellectual pursuits, at times felt a need to reinforce and display their masculinity by undertaking rigorous 'manly' physical activity. Bookwork could be seen as feminine, even effeminate, and around 1900 there was a vogue among male intellectual workers for activities such as mountain climbing and demanding, marathon walks.[31] By the 1890s, a tension has been identified within elite masculinity which opposed the qualities of physicality and intellectualism,

[30] Michael Argles, *South Kensington to Robbins: An account of English technical and scientific education since 1851* (London: Longman, 1964), p. 28.

[31] Hilda Phoebe Hudson (Newnham College, Cambridge) who was placed equal to the seventh wrangler in 1904, had a twin brother with equal mathematical talent who was killed in a climbing accident at a young age, just as he was embarking on mathematical research: M.D.K., 'Hilda Phoebe Hudson, 1881-1965', *Newnham College Roll Letter* (1966), 53-54. Taking dangerous exercise as a means to display masculinity seems to be a persisting need; mathematician James Lighthill (b. 1924) who was taught by Hardy and Littlewood, liked to undertake 'adventure swims' around islands. He recalled one swim that required particular 'nerve and stamina' - around Sark in the south westerly gale which caused the Fastnet disaster: Lewis Wolpert and Alison Richards, *Passionate Minds: The Inner world of scientists* (Oxford: Oxford University Press, 1997), pp. 59-67 (p.63).

privileging the former as the defining virtue of the elite male.[32] Linking to this, John Tosh has argued for a late-Victorian model of manliness which, for its realization, required a forceful exertion of will over wives.[33] In the context of science, there are several examples of collaborative partnerships in which joint work or the work of the female spouse has been presented as solely the man's responsibility. The succeeding chapter will demonstrate this dynamic with regard to Grace Chisholm and William Henry Young; Barbara Becker has illustrated a similar arrangement between William and Margaret Huggins.[34] That Ayrton and other Central men's attitudes were altogether more 'advanced' rested in part on the knowledge that they were secure that their own qualities, and their profession, were gendered unquestionably masculine.

William Ayrton had proved his expertise and stamina by helping to transform the Indian telegraphic network and setting up his own telegraphic laboratory in Japan. Often referred to as 'the nerves of Empire', Britain's global telegraphic network had a moral subtext and its engineers were celebrated for their service to imperialism and their manly courage. This is illustrated, for example, by a series of cigarette cards on 'wireless telegraphy' which were issued in 1909 and emphasised the severity of the conditions that telegraphic engineers faced in their work (figure 3.2). At both Finsbury College and the Central the emphasis was placed firmly on active, practical learning - not feminised, sedentary bookwork. As early as 1886, assumptions that implied just such a gender division had been articulated in an influential book on education:

> in an age when the wonderful growth of physical science and the absorbing demand of material interests are more and more engrossing the thoughts and minds of educated men, it is to devolve on women in some way to supply the loss, and to aid in preserving and transmitting to the civilisation of the future an element of refining culture which it can so ill spare.[35]

Masculinity was also assured in the securement and use of new, often large scale, equipment and instrumentation. At the Central, Ayrton could

[32] '...elite masculine virtues evolved .... into a code of deportment founded on the basis of moral righteousness, aggressive physicality, male sexuality and camaraderie, self-control and stoic attention to duty': Stephen Heathorn, ' "The highest type of Englishman": Gender, War and the Alfred the Great millenary commemoration of 1901', *Canadian Journal of History*, 37 (2002), 459-482 (p. 472).

[33] John Tosh, 'Domesticity and manliness in the middle-class family of Edward White Benson', in *Manful Assertions: Masculinities in Britain since 1800, ed. by* Michael Roper and John Tosh, (London: Routledge, 1991), pp. 44-73 (pp. 51-53).

[34] B.J. Becker, 'Dispelling the myth of the able assistant: Margaret and William Huggins at work in the Tulse Hill Observatory', in Pycior, pp. 98-111.

[35] Orton, pp. 34-35.

display his potent masculinity, not least in the new electrical laboratories that he had specified and fought to have financed. Professor Ayrton had to be 'congratulated', said an editorial in the College journal, before going on to describe the new facility which promised to maintain the Central's, and England's, precedence in the fast-paced world of electrical engineering. The laboratory signalled status, modernity and scale. It was eighty five feet long, fifty three feet wide and contained, amongst other equipment, a power generation and distribution centre, a five kilowatt Ferranti transformer, and a travelling overhead crane to assist in experimentation.[36]

Cultural representations of scientific manliness became more common around turn of century. J.A. Kesiner has argued that the Sherlock Holmes stories, which first appeared around this time, both reflected and constructed a script of active masculinity which aligned manliness with rationality, scientific procedure, observation, factuality and self-help.[37] Conan Doyle admired the work of Edgar Allen Poe, who is generally credited with originating the genre of the detective novel with his 1841 story *The Murders in the Rue Morgue*. Conan Doyle praised Poe (and later French novelist Jules Verne) for producing 'credible effects' within 'incredible story lines' through the use of a knowledge of nature.[38] Although it is certainly the case that Poe's detective, Inspector Dupin, anticipates the character of Sherlock Holmes in the use of analytical reasoning,[39] the later Holmes stories place scientific procedure as essential and constitutive of the Holmes's character. In this way, Conan Doyle created a combination of the 'detective genre' with that of the 'scientific expedition'.[40] H.G. Wells, who had been taught biology and zoology by Thomas Huxley at the Normal School of Science,[41] also presents the scientific man as an ideal of masculinity in his novel, *Ann Veronica*, which is based around the natural science laboratory at Imperial College (of which the Royal College became a constituent). Capes, the rational, plain and trustworthy scientist is contrasted with his

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[36] LGL, 21,907-8 ('The New Electrical Laboratories', *The Central*, 1 (4) (1903), 7-12).
[37] J.A. Kesiner, *Sherlock's Men: Masculinity, Conan Doyle and Cultural History* (Aldershot: Ashgate, 1997), pp. 15-18.
[38] Thomas A. Sebeok and Harriet Margolis, 'Captain Nemo's Porthole: Semiotics of Windows in Sherlock Holmes', *Poetics Today*, 3 (1) (1982), 110-139 (p. 110).
[39] See Shawn Rosenheim, ' "The King of 'Secret Readers' ": Edgar Poe, Cryptography, and the origins of the Detective Story', *English Literary History*, 56 (2) (1989), 375-400.
[40] Sebeok and Margolis, p. 112.
[41] Wells, who much admired Huxley, Darwin's vocal supporter and agitator for scientific education, had received a scholarship to train as a science teacher. This scholarship provided free tuition and a stipend of a guinea a week. Norman and Jeanne Mackenzie, *The Life of H.G. Wells: The Time Traveller* (London: Hogarth Press, 1987), p. 53.

foppish, effeminate rival who feels uncomfortable in the laboratory.[42] Although the heroic myth of the Victorian engineer had become a part of the legitimising myths of industrial society earlier in the century (reflected, for example, in the biographies produced by Samuel Smiles)[43] this later characterisation was different in the emphasis it placed on scientific method as applied to all aspects of society and as a paradigm of manly citizenship. A leader in *The Times* welcomed the proposed establishment of Imperial College because it promised 'science systematically applied to the arts and industries of daily life'. The writer envisaged that the new educational establishment would become

> a model and a centre of light leading the whole Empire ..... We talk a great deal about science, and we all pay it a certain amount of homage with our lips; but we still withhold from it in too large a measure the homage of our heads and understandings. We have not yet learnt to see in it the influence, the spirit, and the force which really lie at the root of all effective action in the modern world.[44]

Social reformer Beatrice Webb, who was active in the scientific circles of Thomas Huxley and others, recalled that these men of science held an 'almost fanatical faith ..... that it was by science and science alone that all human misery would be ultimately swept away'.[45]

For *Nature*, commenting on a report by the British Association for the Advancement of Science, the urgent issue was industrial competition between nations and this took on a military flavour (the soldier, like the engineer, was indisputably male): 'we are in the midst of a struggle in which science and brains take the place of swords and sinews; the school, the university, the laboratory and the workshop are the battlefields ...'.[46] It was this kind of thinking which informed one level of support for the eugenics, a movement which only gained momentum in the years preceding the first world war. Hertha was present, alongside scientific notables Norman Lockyer, William Ramsay, Arthur Schuster and Archibald Geikie, at the inaugural International Eugenics Congress held in the Great Hall of the University of London for five days in 1912.

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[42] Foppish Manning, visiting the laboratory, 'carried a cane and a silk hat with a mourning-band in one grey-gloved hand; his frock coat and trousers were admirable ..... The low ceiling made him seem abnormally tall'. However, the heroine admired scientist Capes and 'felt him as something solid, strong and trustworthy': H.G. Wells, *Ann Veronica* (London: Everyman/J.M.Dent, 1943, repr.1999), pp. 196-7 and p. 130.

[43] See Robin Gilmour, *The Victorian Period: The intellectual and cultural context of English literature, 1830 - 1890* (Harlow: Longmans, 1993), p. 31.

[44] 'At last there seems a fair prospect that ...', *The Times*, July 3 1905, editorial/leader, p. 9.

[45] Mackenzie, *Life of H.G. Wells*, p. 55.

[46] 'Universities and the State', *Nature*, 70 (1812) July 21 1904, News, p. 271.

At the congress dinner, they heard principal speaker Arthur Balfour argue

> '.... that a feeble-minded man, even though he survive, is not so good as the good professional man ...... In any case we are scientific or we are nothing .... I am one of those who base their belief in the future progress of mankind, in most departments, upon the application of scientific method to practical life'.[47]

For Grace and her husband, eugenics was a way to ensure the continuance of an intellectual elite; for Hertha and her peers in practical science, it was about using science as an instrument to bring about a more rational, efficient society. Norman Lockyer was seeking to realize similar ambitions when he established the British Science Guild in 1905, an association of professional scientists, including Ayrton and others, concerned to promote the role of science in society.

The Central Institution

The professors at the Central were keen to present themselves as part of this modern, meritocratic scientific movement not least because it enabled them to build credibility at a time when their material practices and their integrity were not yet fully accepted. The College was not immediately successful in attracting students and it was not until the 1890s that the situation improved. Furthermore, the practical methods of the College, especially as applied to mathematics, were initially a subject of controversy which even reached the pages of *The Times*. At Finsbury, John Perry had introduced the rounding off of decimals to approximations in recognition of the needs of engineers and pioneered the use of squared paper to facilitate easier production of results.[48] The Central's adoption of a similarly pragmatic approach was not uncontentious. In the opinion of one letter writer to *The Times*, 'practical mathematics' was an innovation suggesting 'an appalling depth of ignorance', to which a colleague of Ayrton's at the Central, chemist Henry Armstrong, responded that the correspondent simply could not 'understand the modern tendency to be practical'.[49] The merits of practical versus pure mathematics were a topic on the letters page again in 1911. Henry Spooner suggested that the differing approaches of the universities and the engineering colleges on this matter accounted for the

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47 *The Times*, 'Aspects of Eugenics', July 25 1912, p. 9.
48 Gooday, 'Teaching Telegraphy', p. 99.
49 Henry E. Armstrong, 'Technical Education in Ireland', *The Times*, June 11 1901, Letters to Editor, p. 12. The dispute centred on a new scheme of technical education, like that at Finsbury, being introduced into Ireland.

small number of university-matriculated students entering engineering and that 'most engineering colleges have for years wisely realized that mathematics, instead of being an abstract discipline, should become the means of applying truths to the everyday affairs of the world in which we live'.[50] The opposing view was put by Grace's husband, William Young, who wrote that 'to substitute the mathematics of .... the engineer for that of the expert mathematician would resemble the behaviour of a man who should insist on having a bad watch because of the variations in the equation of time'.[51]

There was a moral dimension to this dispute, centring on how the world should be properly represented and measured, and who was best qualified to do so. Was the real bringer of truth the engineer, or the exponent of a purer, more precise mathematics? Tensions of class can also be discerned, as the 'practical' men argued against the long standing hierarchy that, in England at least, associated manual labour with the lower classes and intellectual labour with the elite. The case of the engineer to be the embodiment of morality and truth could be further undermined by those adhering to an older notion of the scientist as a disinterested investigator seeking knowledge for its own sake, not for any reward that it might bring. Ayrton was dismissed by one of his professorial colleagues as 'partial', 'impelled into science through contact with Sir William Thomson', and 'a worker chiefly at its technical and commercial fringe rather than its depths'.[52] Both Ayrton and Perry worked as practising engineers, accepted consultancy work and patented many instruments. Ayrton was aware that his interest in business was, for some, at the least a distraction if not a problem for his work. He wrote that 'the stereotypical University Professor thinks that I went, and am still going, quite outside my province as an engineering professor in inculcating on my students that an engineer, no matter how distinguished his scientific attainments ... is really a failure if the concerns that he has to engineer are not financially successful'.[53]

To argue that the presentation of a modern, meritocratic professionalism facilitated the professors at the Central in their support (vocally at least) for women's equality seems to be to deny the explanatory model of the increasing professionalisation of science as a barrier that kept women

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[50] Henry J. Spooner, 'The Education of Engineers', *The Times*, July 19 1911, Letters to Editor, p. 24.
[51] LUSA, Young Papers, D140/35/20 (William Young's notes).
[52] Armstrong, 'Mrs Hertha Ayrton', p. 801.
[53] LGL, 21,868/10.

out. This process is usually linked to Darwinian/evolutionary influences amongst the new professionals which led them to discount woman's capacity for scientific pursuits. This conviction was certainly held by sections of the scientific community, including professor of chemistry Henry Armstrong. However many other 'scientific naturalists' did not make this connection and staunch Darwinists such as Ayrton, Hertha, and editor of *Nature* Norman Lockyer, took an opposing view. Despite being a strong explanatory tool, the professionalisation model does not account for the vocal support for women exhibited by many sections of the science and engineering community. Lockyer campaigned in his journal in support of the admission of women to learned societies and for the equal treatment of intellectual work, irrespective of the sex of the producer. When Hertha was proposed for a Royal Society fellowship, nine prominent male fellows signed and supported her nomination. When Armstrong used his report for the 1904 Mosely Education Commission to argue against women's intellectual equality and for the 'ruinous effect' of female science teachers, an editorial in *The Central* contradicted him decisively: 'Professor Armstrong's argument from evolutionary principles seems to us absolutely fallacious - he would probably say that this is due to our inability to appreciate them'.[54]

It seems clear that the processes of professionalisation need to be unpackaged and refined in order to reveal the complexity hiding behind the term. The new engineering and academic professors were keen to distinguish themselves from the elitist ideology and exclusive practices characteristic of much of Cambridge-dominated science and of traditional sections of the Royal Society.[55] To support women in the interests of 'fairness' and 'justice' was logical and supportive of their cause, and it was from similar principals that many of these scientific 'modernisers' backed votes for women. This is also an important factor in the public relations strategy of Hertha and William Ayrton. Both were keen to deny in public any hint of collaboration or collusion in their work, only too aware of the gendered interpretations given to collaborators of differing sex. As Hertha wrote of Margaret Huggins 'she has done some splendid work on astronomy herself, with her husband,

[54] LGL, 21,907-8 ('The Mosely Commission', *Central*, 1 (4) (June 1904) 122-126). The Mosely Commission reported on education in America. Henry E. Armstrong (1848-1937), professor of chemistry, is remembered as an educational reformer who lobbied for heuristic learning.
[55] For example, J.J. Thomson, who was sceptical of female intellectual capacities and denied female researchers equal access to the Cavendish Laboratory; and William Huggins and Joseph Larmor, members of the Council of the Royal Society, who were critical that commercial interests tainted scientific work and were strongly opposed to the admission of women.

and has not had a bit of recognition for it just because no one will believe that if a man and a woman do a bit of work together the woman really does anything'.[56]

The politics of collaboration

Yet the Ayrtons' public disavowal of collaboration was not entirely true in reality (and collaboration is, after all, a flexible term that can encompass a myriad of types and extents of shared involvement). For example, when ill health struck Ayrton in 1903, just as he had been commissioned to report on searchlights for the Admiralty, Hertha increasingly took on the major part of the work, experimenting at the Central with her husband's students and staff.[57] The research resulted in four reports, three of which were published under Ayrton's name alone. The work also resulted in an article, attributed to Hertha, in the *Times Engineering Supplement*. In addition, Sharp alludes to Ayrton contributing to Hertha's papers[58] and a colleague at the Central remembers that 'being both enthusiastic and having cognate interests, they constantly worried each other about the work they were doing'.[59] Hertha's important investigations into the electric arc were a continuation of her husband's work; her 1903 book which resulted from these researches illustrates clearly the assistance received from staff at the Central, in particular Thomas Mather who made fundamental contributions to the design of the experiments.[60] The attributing of credit and 'ownership' of research is a complex phenomenon and recent scholars have debunked the idea of a single, heroic, lone experimenter. Who 'takes the credit' for a discovery or piece of research can be a political, as well as a scientific, issue; that women have been classified as 'assistants' has been well documented by historians of women and science.

Hertha's researches on the electric arc were carried out in her husband's laboratories at the Central Institution. Arc lights were used for searchlights, streetlights and other public lighting, as the light that they

[56] Sharp, *Hertha Ayrton*, pp. 186-7.
[57] LGL, 21,955 (T. Mather, 'William Edward Ayrton', *The Central*, 7 (21) (1910), 70-80 (Memorial issue to W. E. Ayrton).
[58] Sharp, *Hertha Ayrton*, p. 150.
[59] Armstrong, 'Mrs Hertha Ayrton', p. 801.
[60] Research required burning carbons over long periods of time, watching for minute changes. Mather supervised the first set of experiments and designed succeeding ones which incorporated a mirror which projected the phenomenon onto a 'screen' of cartridge paper: Hertha Ayrton, *The Electric Arc* (London: The Electrician Printing and Publishing Company, 1903), p.352.

produced was too harsh for indoor home use. To strike the arc a high voltage was established between two carbon rods a short distance apart; however the result was unstable and there were additional problems of noise, sputtering and hissing. By experiment and observation, Hertha discovered that one of the conditions of the steady burning of the arc was the shape assumed by the ends of the carbons; by shaping these to a certain dimension the arc's performance was improved considerably. Her major theoretical insight was to explain the hissing and instability of the arc as a result of air rushing to the tip of the positive electrode, oxidising the carbon and forming a crater. This led her to establish a relationship between the voltage drop across the arc, its length and the current that became known as the 'Ayrton Equation'.[61] Despite this lengthy and well-received investigation, Hertha had no official role or status at the Central Institution and her presence was dependent on her being 'wife of the professor'. When her husband died in 1908, she had no further dealings with the College and, instead, enlarged her home laboratory to better cater for her needs. However, the loss of a viable and credible experimental space was to have serious implications for the reception of Hertha's work, as will be demonstrated in chapter five.

Femininity confined to the margins

Despite the vocal sympathy for women's equality in the sciences displayed by important sections of the science and engineering community, Hertha encountered obstacles in attempting to negotiate an identity as a professional engineer like, and alongside, her male peers. Although the professors may have been supportive in principle (and indeed the College's 1878 foundation documents show that the City and Guilds initiators planned an institution catering for both sexes),[62] the later aims and material practices of the College quickly militated against this initial agenda. The priority of the Central (which provided a higher level of training than that offered at Finsbury and to which Finsbury students often graduated) was to train professional men and become the equal in prestige of the more-established universities. Women, especially middle class women, were still associated with amateur status and the

[61] IEE, 'The Arc Lamp', <http://archives.iee.org/about/Arclamps/arclamps.html> [accessed February 11 2005]

[62] In 1878, the executive committee of the City and Guilds of London Institute recommended a national scheme of technical education including a central institute for advanced instruction and research in science and technology, and the development of local trade schools. The 1883-4 programme states as one of its objects the education of 'Persons of either sex who wish to receive a scientific and practical training...', LGH, 21,861 and 21,970.

acquisition of learning for learning's sake; as a result they became marginal to the College's preferred image and, arguably, threatening to college aims. Indeed, women were rarely recruited to the Central and no names recognisable as women's can be found on existing engineering student registers to 1899.[63] Despite Hertha's periodic researches at the Central from around 1895 to 1904, which included her well-known investigations into the electric arc, her presence is rarely noted in any extant college archive. Hertha is mentioned briefly as a collaborator in an obituary of her husband in the college journal;[64] after her death this also carried a review of Sharp's *Memoir* published in 1926.[65] This relative 'invisibility' is significant when it is remembered that Hertha's work there, aided by Central students, led to the award of a prestigious Royal Society Medal (awarded in part for a later investigation into sand ripples). Despite Hertha's informal status at the Central, this was surely something to publicise for a college striving to win credibility as a professional institution offering a university-equivalent education? Indeed, promoting the original work of its students was an important propaganda tool for the Central in its bid to win credibility and prestige.[66]

This reticence over Hertha's links to the College, and the absence of any significant number of women students, is to be explained in the context of the Central's primary purpose, as outlined in its 1884 Scheme for Organisation. This 'mission statement' stressed that the College's aim was 'to point out the application of different brands of science to various manufacturing industries' noting that 'in this respect the teaching will differ from that given in the Universities and in other institutions in which science is taught rather for its own sake than with the view to its industrial application'.[67] Students of the Central were being trained to take jobs at middle to senior manager level in electrical, construction and other industries, and could be sent to the furthest reaches of Empire. Just as the heroes of popular Edwardian novels were presented as achieving manhood by leaving women and home to travel overseas and test themselves in the comradeship of men,[68] so 'graduates' of the Central

[63] LGL, 21,868/10.
[64] LGL, 21,955 (T. Mather, 'William Edward Ayrton').
[65] Soloman.
[66] Graeme J. N. Gooday, 'The Premisses of Premises: Spatial issues in the historical construction of laboratory credibility', in *Making space for science: Territorial themes in the shaping of knowledge*, ed. by Crosbie Smith and John Agar, (Basingstoke: Macmillan, 1998), pp. 216-245 (p. 238).
[67] Ibid., p. 238.
[68] For example the work of H. Rider Haggard and R.L. Stevenson. These narratives have been interpreted as character building tales which comprise a tradition of writing important to supplying

were prepared for taking on strenuous and demanding tasks, often in foreign lands. The College had its own Employment Bureau and, once armed with their Diploma, 'Central men' took posts with the Royal Survey, electric supply and railway companies, lift manufacturers, dam construction companies and similar organisations.

Within this self-consciously manly environment, even the merest hint of femininity required explanation. When *The Central* described the College's research on a vacuum cleaner, the author felt it necessary to excuse this feminine-related subject 'occupying valuable space' by emphasising that 'the profession of an engineer is the art of directing the sources of power in Nature for the use and convenience of men'.[69] The Central did not even train individuals to be teachers (an acceptable role for women) as that was the task of its partner college in South Kensington, the Royal College of Science. Women were more visible here (especially in seasonal summer courses) but, as noted in a survey of opportunities for women published in 1897, 'a fair number of women have now received an excellent training in natural science, holding the BSc of Cambridge or London (but) hardly any employment is open to such women save that of science mistress'.[70] A woman in science was one thing, a woman being trained to apply science to industry was quite another.

Yet the rarity of women in either of these spheres could easily turn into an attack on a woman's femininity and sexual desirability. By the early 1920s women were more visible but, as a poster/cartoon illustrating different kinds of female university flappers indicates, science and medical students were still viewed as odd. (Figure 3.3) As opposed to the young and nubile 'Slade' and 'Arts' flappers, the science and medical women are portrayed as aged and unattractive; for science, the word 'flapper' is in quotation marks as if to imply that it was not really possible to be a science student *and* a young, modern, desirable woman. It will be discussed in chapter seven how older, menopausal women became figures of ridicule - even of hate - among sections of the medical and general community; presenting the 'science flapper' as aged may have been another way of highlighting her ridiculousness. The representation of the 'medical flapper' is also unflattering, even menacing; she is

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British Imperialism with an energising myth. See Martin Burgess Green, *Dreams of Adventure: Deeds of Empire* (London: Routledge and Kegan Paul, 1980), pp. 3-8.

[69] LGL, 21,907-8 ('The Vacuum Cleaner', The *Central,* 1 (4) (1904), pp. 146-8).

[70] C.S. Bremner, *Education of girls and women in Great Britain* (London: Sonnenschein, 1897), p. 221.

portrayed as a dark, gaunt figure with the large nose and abundant hair (caught up in a scarf) suggestive of stereotypical Jewishness. The scalpel held in her hand suggests she is about to perform a (diabolical?) dissection. Fear of the Jewish 'other' has been discussed in chapter one with reference to Hertha's experiences at Girton. It has also been noted that the emergence of an increasingly successful, educated and financially-comfortable Jewish community constituted a challenge and source of unease to sections of Anglican England. The figure of the Jew was 'constantly invoked at this moment when Christian authority was under heightened scrutiny in an era of religious scepticism due to Darwin'.[71] The image of the 'medical flapper' seems to combine this fear of the Jewish 'other' with anxiety over women stepping beyond their prescribed roles and competing in 'men's' scientific arenas. This kind of representation would have conveyed worrying subliminal messages to middle-class Jewish women such as Hertha and may be another clue as to why she felt it necessary to renounce Judaism on her marriage.

Engineer or lady of science ?

Hertha has been remembered as a 'persistent experimenter'.[72] She enjoyed being in the laboratory carrying out practical investigations and consistently applied her inventive and engineering skills to the development of devices and equipment. As she confided to a relative of Marie Curie, when working in her laboratory she felt that for her 'la science est toujours la grande calme, un réfuge contre tout les maux'.[73] Her first design for a sphygmometer (device for measuring the pulse) was produced while she was still a student at Girton, in later life she designed various devices including an anti-gas fan for use in the trenches during World War One; her final years were spent in trying to adapt this for application to ventilation in ships. From her letters, her inventiveness and the many patents that she took out, it is clear that she would have liked to lead a career much like her husband's, but the identity of a modern, professional engineer was indisputably male, despite women's long (and until recently) largely invisible history as inventors and producers of technology.[74] The engineers at the Central contrasted

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[71] Cynthia Scheinberg, 'Re-mapping Anglo-Jewish literary history', Victorian Literature and Culture, 27 (1) (1999), 115-124 (p. 118).
[72] Tattersall and McMurran, p. 86.
[73] Paris, Bibliothèque nationale, Papers, Naf. 18443, fol. 310 (letter, January 7 1912).
[74] Autumn Stanley writes that until the late 1970s 'no book had ever been done on women as inventors. Not only were there no books, but even book chapters and articles on women as contributors to technology were vanishingly rare'. Stanley's pioneering book provides comprehensive

themselves with the older figure of the disinterested research scientist, and the newer pure mathematician lost in 'useless' abstraction, by dint of their active, manly citizenship. Action in the world was central, based on empirical knowledge, measurement, trust and a rejection of any science based on metaphysical interpretations.

Londa Schiebinger, Evelyn Fox Keller and others[75] have demonstrated how, in the seventeenth century, 'femininity' became the antithesis of the new, virile 'masculine' science of the emerging Baconian Royal Society. 'Feminine' became descriptive of a contemplative, deductive, passive style of investigation that was to be expunged from the new values and epistemological stance of modern, active, experimental science. A parallel process can be discerned at the end of the nineteenth century as the new, thrusting professional lobbied for credibility with his purer, elitist rival. But more than this, the modern engineer applied his science for the betterment of the world and sought legitimacy for his science (which to the old school was tainted by a compromising commercialism) with ideals of service .Their science was not only to be put at the service of men, but of country too. For example, at turn of century Central students created 'The Electrical Engineers' voluntary corps, sanctioned by the War Office, which concerned itself with electricity as an agent of warfare.[76] Notions of service had, since the mid-Victorian period, strong feminine connotations; women's ideal role was to remain in the private sphere supporting their families and communities by performing the role of 'helpmeet' and undertaking philanthropic acts. The engineers sought to put a masculine (and at times military) face on an ideal of service that was directed out into the world; a woman in their midst may have been compromising to this image. The ETU banner, bearing the words 'light and liberty', showing men in the their work attire at the service of an abstract and female electricity/nature, conveys neatly the gendered roles within this new profession of engineering. It also suggests why it was so hard for practitioners and observers to accept Hertha as a scientific professional no different from her male peers. With few examples or narratives of feminine technical or engineering professionalism with which to align a female scientist, Hertha was instead classified with the other 'female' element of the ETU banner - the extraordinary angel or

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redress: Autumn Stanley, *Mothers and Daughters of Invention: Notes for a revised history of technology* (New Brunswick NJ: Rutgers University Press, 1995), p. xvii.

[75] Schiebinger, pp. 136-144; Fox Keller, pp. 43-65.

[76] LGL, 21,9956 ('The Electrical Engineers', *Central Gazette*, 2 (1) (1899), 18-20). Their interests included electricity for harbour defence, mines and searchlights.

goddess of natural forces, an elision of woman scientist seeking to control nature *with* nature itself.

The personification of nature in female form is a long standing phenomenon. In her definitive text, *Monuments and Maidens,*[77] Marina Warner finds a prosaic reason for this kind of female allegory in the common relation of abstract nouns, especially of virtue, to the feminine gender in Indo-European languages. However, her more profound analysis reveals that recognition of the symbolic order, inhabited by ideal, allegorical figures, as opposed to the actual order, is often dependent on the unlikelihood of women practising the concepts that they represent. And (as the example of the ETU banner with its depiction of real men and abstract 'woman' demonstrates) the female form tends to be perceived as generic and universal, the male as individual, even when expressing a generalised idea.[78] Londa Schiebinger has applied this analysis to representations of science and has demonstrated just how common female personifications of science, and branches of science, were in the seventeenth and eighteenth centuries.[79] These images were often equipped with the latest scientific accoutrements, such as a barometer, telescope or vacuum jar, and appeared typically on the frontispiece of scientific texts. In this way, science was pictured as feminine not least because the scientists, 'the framers of this scheme' were male and 'the femme Scienta plays opposite the male scientist'. Such images also buy into the discourse of 'the muse' as 'the scientist imagines that a feminine science leads him to the secrets of nature or the rational soul'.[80] But when the scientist is female, this arrangement has serious implications.

Despite her attempts to present herself as a professional scientist, Hertha's femininity was foregrounded constantly and she was often typecast as a supernatural 'heroine' of science. A one-time president of the IEE used lyrical in preference to scientific language to describe her 'beautiful experiments' on wave formation, recalling how Hertha made herself 'the mistress of sand ripples' and describing how the movement of sand 'at her will formed itself into beautifully uniform patterns'. Adding to the image of Hertha as some extraordinary example of womanhood, A.P. Trotter continues to tell how he read one of her papers to his

[77] Warner, p.xxi .
[78] Ibid., p. xx.
[79] Schiebinger, pp. 136-150.
[80] Ibid., p. 134.

students and showed a lantern-slide portrait of the author in an attempt 'to describe her charming personality'.[81] The difficulty of accommodating a female scientist within any other, more prosaic narrative, is illustrated by a popular text, *Woman in Science,* which was published in 1913 and went through a number of editions. In his preface, H.J. Mozans describes how his mind turned to women during leisurely wanderings through the 'famed and picturesque land of the Hellenes'. Here, inspired by representations of Aspasia 'the virgin goddess of wisdom and art and science', he was moved to investigate the intellectual achievements of women. In Mozans' flowery prose, descriptions of real, nineteenth-century scientists are often couched in language more usually descriptive of mythical female deities. Entomologist Eleanor Ormerod is reported as being described by the university official who conferred an honorary doctorate upon her as 'entitled to be hailed as the protectoress of agriculture and the fruits of the earth ..... a beneficent Demeter of the nineteenth century'.[82] In similar vein, Marie Curie's experimental abilities are likened to magic as 'before her deft hands and fertile brain difficulties vanished as if under the magic wand of Prospero'.[83]

The difficulties of a woman taking on the new - but ordinary - role of a professional scientist at turn of century can be gleaned from Mozans' concluding remarks. Here he generalises that men will 'continue as specialists as long as the love of fame, to consider no other motives for research, continues to be a potent influence in their investigations', while women will forego 'long and tedious processes' for the 'proper apprehension of higher and more important truths'. This was in keeping with a thread within contemporary thought which pointed to woman's greater purity and nobility and stressed her role in tempering the excesses of man.[84] For Mozans, men reached conclusions through the application of plodding, inductive methods, while women naturally used deduction and 'a kind of intuition, coupled with (their) more pronounced idealism'. As result

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[81] IEE (Trotter, pp. 569-591).

[82] H.J. Mozans, *Woman in Science, with an introductory chapter on woman's long struggle for things of the mind,* 3rd edn (Notre Dame, I: University of Notre Dame Press, 1991), p. 252. Eleanor Ormerod (1828-1901) was a self-taught investigator, author and public speaker; from 1882-1892 she was consulting entomologist to the Royal Agricultural Society, she was a fellow of the Royal Meteorological Society and an examiner in agricultural entomology at the University of Edinburgh, which in 1900 warded her the first honorary LL.D it had ever offered to a woman. Marilyn Bailey Ogilvie, *Women in Science, Antiquity through the Nineteenth Century: A Biographical dictionary with annotated bibliography* (Cambridge, MA: MIT Press 1991), pp. 142-143.

[83] Mozens, p. 224.

[84] Burstyn, pp. 109-110.

.... just at the critical moment, when men of science would rather discover a process than a law, when they are so preoccupied with the infinitely little that they lose sight of the cosmos as a whole .... when, like Plato's cave men, they have so long groped in darkness that their powers of vision are impaired, then it is that woman, 'The herald of a brighter race', comes to the rescue ..... For women, as a rule, love science for its own sake...[85]

It is interesting that Henry Armstrong's obituary in *Nature* criticised Hertha within just these terms of reference, maintaining that 'though a capable worker, she was a complete specialist and had neither the extent nor depth of knowledge, the penetrative faculty, required to give her entire grasp of her subject'.[86] Hertha's refusal to be placed on a pedestal of science, preferring to be a professional worker rather than a sanctified, exceptional 'mistress' or 'lady' of science, may have been part of the problem for her unsympathetic obituarist. After all, if access to science was conceived as possible for only special women - women exceptional within their sex - then female scientists would be rare; open the doors of science to women as everyday professionals and significant numbers of 'everyday' women may enter. Armstrong held well-known views about the incompatibility of women and science and was vocal in his opposition to women's admission to the Chemical Society. He was particularly ungenerous in his obituary of Hertha, accusing her of failing in her wifely duties: 'He (William Ayrton) should have had a humdrum wife .... who would have put him into carpet-slippers when he came home, fed him well and led him not to worry either himself or other people, especially other people; then he would have lived a longer and a happier life and done far more effective work...'[87]

In the Mozans passage quoted above, women seem to represent an antithesis to the modern, technological and commercial concerns of practical science and engineering. Even female scientists are charged as having, by dint of their female nature, a higher calling and the ability to temper the myopic scientific tendencies of men. This signification was in keeping with a thread in late nineteenth century society which reacted against modernity and material growth and characterised the industrial world as alienating.[88] Femininity was often the pivot around which such concerns were articulated, as in the idealised role prescriptions for

[85] Ibid., pp. 408-410.
[86] Armstrong, 'Mrs Hertha Ayrton', p. 801.
[87] Ibid.
[88] Martin J. Wiener, *English Culture and the decline of the industrial spirit,1850-1980* (Cambridge: Cambridge University Press, 1981), pp. 5-18

women in the work of writers such as Ruskin and Kingsley. This thread was fully articulated in Germany, where modern technology and industry were seen as the incarnation of masculine principles which subjugated individuality and diversity to standardised industrial practice. Here women pointed to their authenticity and ability to reconnect men with nature as part of their demands for increased influence and emancipation.[89] In England too, the ideal of womanhood as something pure and noble in contrast to the material, masculine concerns of the modern world was a factor in arguments against female suffrage.[90] In attempting to find a place for themselves in science, earlier women had sometimes colluded with supernatural representations of themselves and identified with the feminine icon. Both astronomer Maria Cunitz and natural philosopher Emilie du Châtelet placed themselves amongst the muses and not within depictions of actual (male) scientists on frontispieces of their work.[91] In the nineteenth century too, women used similar methods to negotiate their position in science. Mathematician Mary Somerville preferred to remain uncontroversial and was happy to present herself as a 'lady' of science, in keeping with contemporary ideas of gendered intellect. With due feminine modesty, Somerville wrote that as a woman she was not original herself, but only an interpreter and presenter of the original work of men. Kathryn Neeley argues persuasively that this was a useful strategy for a female mathematician of her class and age, rather than a strongly-held philosophical commitment.[92] Similarly, anthropologist Clémence Royer argued that women had a natural 'genius peculiar to themselves' and that they contributed to science in a feminine way, different from men.[93] For Hertha, such a position would have been unthinkable; she argued strongly against any biological difference between the sexes and felt that it was only social handicaps that needed to be removed to facilitate women's involvement in activities dominated by men. Throughout her life, Hertha reiterated constantly her 'plea for equality of treatment of intellectual work without regard to the sex of the worker'.[94]

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[89] Frevert, pp. 107-137.
[90] The elitist, anti-state, anti-technical position of some 'feminist' but anti-suffrage opinion has been demonstrated by Lucy Delap: ' "Philosophical vacuity and political ineptitude' *The Freewoman's* critique of the suffrage movement', *Women's History Review*, 11 (4) (2002), 613-630.
[91] Schiebinger, p. 144-146.
[92] Kathryn A. Neeley, *Mary Somerville: Science, illumination and the female mind* (Cambridge: Cambridge University Press, 2001), p. 188.
[93] Joy Harvey, *"Almost a Man of Genius": Clémence Royer, feminism and nineteenth-century science* (New Brunswick, NJ: Rutgers University Press, 1997), p. 53.
[94] Exeter University, Library (Special Collections), correspondence Hertha Ayrton to Norman Lockyer, January 16 1911.

Conclusion

Whether researching the electric arc under the auspices of her husband's department at the Central, or in collaboration with him in the development of searchlights, Hertha strove to retain an independent identity. Despite her efforts, the marginal status of women at the Central created difficulties for her in exploiting her well-received work on the electric arc to its full potential as a stepping stone to other experimental opportunities. In keeping with her convictions on sexual equality, Hertha was a political strategist and firm defender of her work; she did not present herself as a deferential 'gentlewoman of science'. Her correspondence shows that, from the start, she was not afraid to argue forcefully for her work, for example defending her observations on the electric arc against Sylvanus Thompson's well-meaning criticism[95] and engaging in bad-tempered correspondence with referees of her Royal Society papers (as will be illustrated in chapter seven). Neither was she afraid to argue in public. *The Times* letters page contained a firm rebuttal by her of criticism of her anti-gas fans[96] and when William Ramsay suggested in the *Daily Mail* that women scientists do their best work when working under the guidance of men, Hertha's reply was effective - and personal:

> Collaboration is apparently not a womanly but a human characteristic ... In testifying to the stimulus provided by collaboration, Sir William Ramsay speaks from a wide experience denied to me; for most of his own work has been done 'when collaborating with a male colleague' and one can imagine the fervour with which he worked 'with Lord Rayleigh and for Lord Rayleigh' at the discovery of argon.[97]

This assertiveness is conveyed in Armstrong's obituary when he contrasts Hertha's possession of 'the vigour of Wotan's masterful

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[95] IEE, correspondence Hertha Ayrton to Sylvanus Thompson, May 27, 1899.

[96] Hertha Ayrton, 'Anti-Gas Fans: Their utility in France', *The Times*, May 10 1920, Letters to Editor, p. 8.

[97] Sharp, *Hertha Ayrton*, p. 246. Argon gas had been discovered by William Ramsay and Lord Rayleigh in 1894 and both were later awarded a Nobel prize. Ramsay, Professor of Chemistry at University College London, was known for his anti-feminist views.

daughter Brunhilde' with the (preferable) charms of Ayrton's first wife who was a feminine and 'ethereal being'.[98]

Hertha was not, however, entirely successful in adopting the identity of 'engineer' in the face of the conceptual problems facing technical women outlined above. On her death, *The Times* headed its obituary 'A distinguished *woman scientist*'[99] (my italics); this was a common representation of Hertha and one which she would usually accept. Although Hertha was an experimenter and designer of technology, engaged in engineering and invention to the end of her life (she took out patents from 1883 to 1920), the title 'scientist' could also reflect her interests. As the press preferred to report her activities under the banner of 'lady' or 'woman' scientist, Hertha may have acquiesced to this title in response to the evident tension between the term 'engineer' and 'woman'. (Indeed, this was a tension that she may have sensed herself). This, in turn, suggests the difficulties that she faced (discussed further in chapters five and seven) when trying to participate in engineering at the level of professional practice. Mary Somerville perfected the role of the gracious lady of science, seldom demanding rights for herself on a par with men and happy to have her bust placed in the Great Hall of the Royal Society, even if she herself was not welcome. For Hertha, this was not enough; she wanted to be admitted in person, just as she wanted to be accepted as a working, scientific professional alongside her peers. However for a woman at the turn of the nineteenth century, there may have been room on the pedestal, but the new profession of engineer was a wholly masculine concern.

[98] Armstrong, 'Mrs Hertha Ayrton', p. 800. Armstrong cast Matilda Chaplin, Ayrton's first wife, in the role of the more gentle and 'feminine' Melisande.

[99] *The Times*, 'Mrs Hertha Ayrton: A distinguished Woman Scientist', August 28 1923, Obituaries, p. 11.

Figure 3.1

Reproduced from Jane Beckett and Deborah Cherry, eds, *The Edwardian Era* (Oxford: Phaidon, 1987), p.22

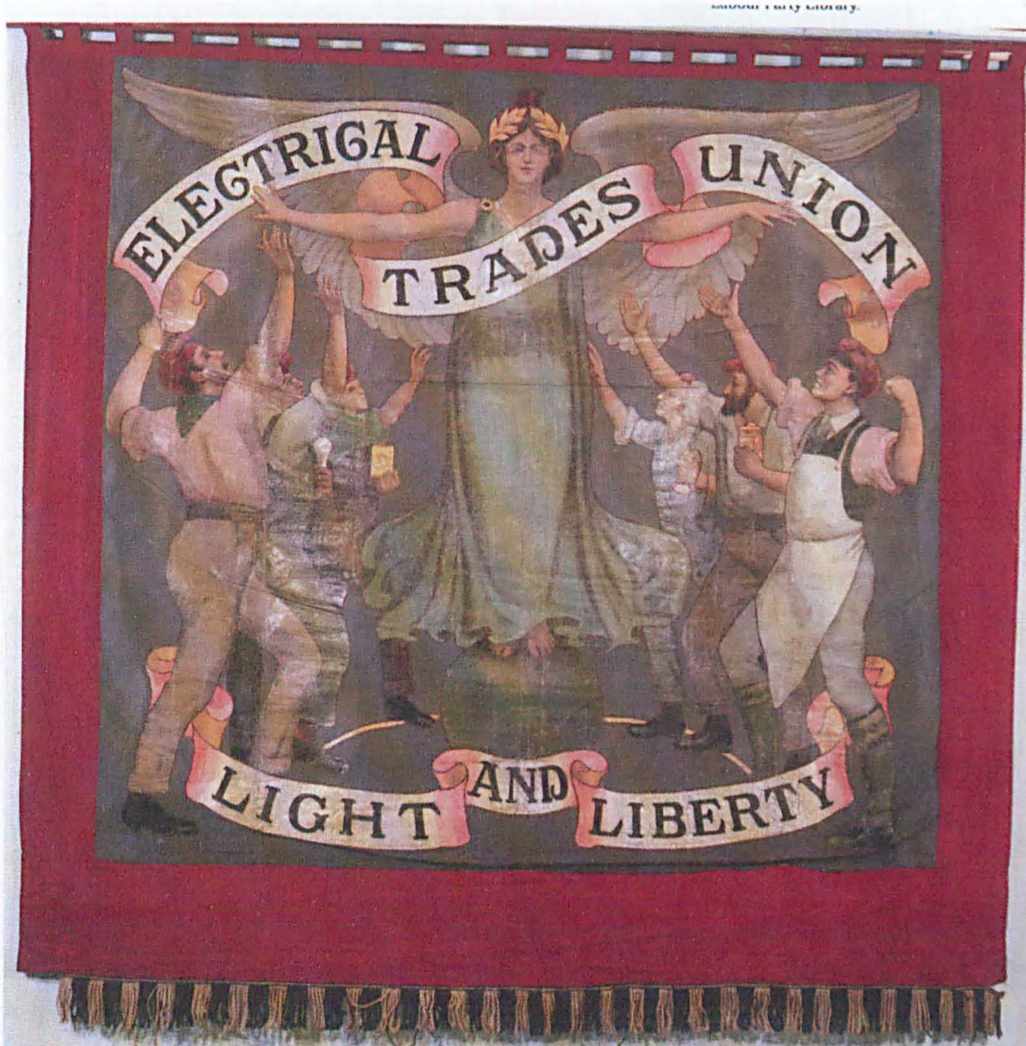


Figure 3.2

From Set of 25 cards on 'Wireless Telegraphy' issued by Lambert & Butler in 1909.

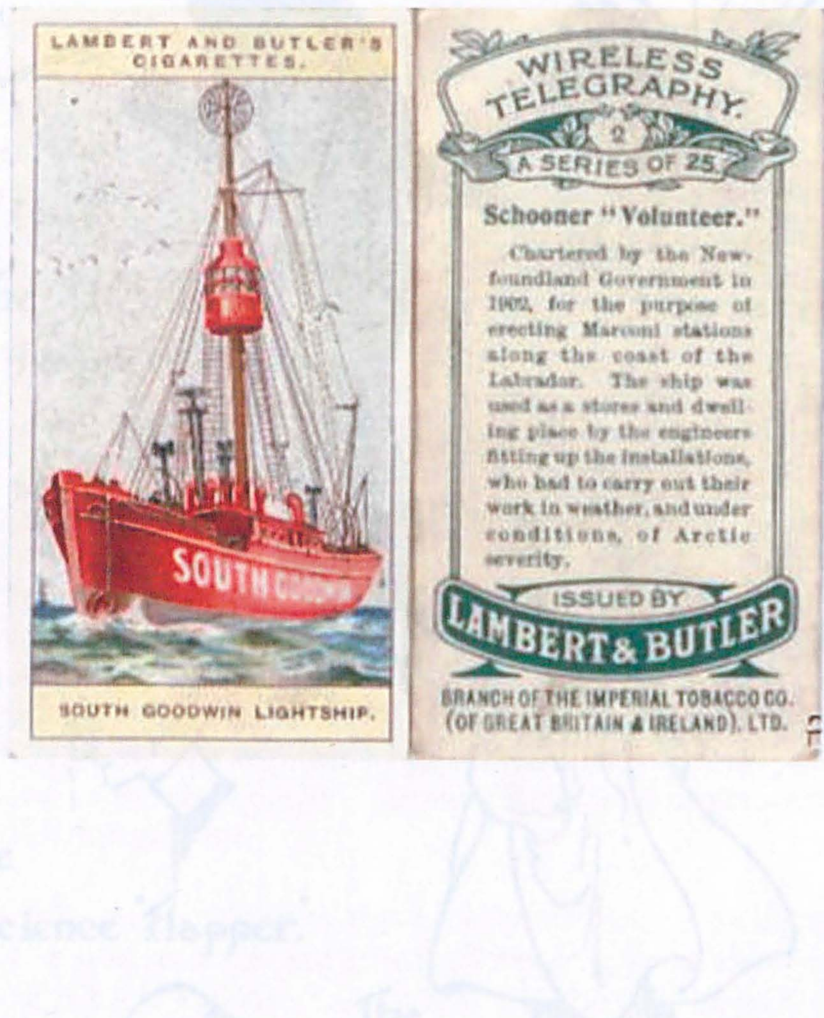
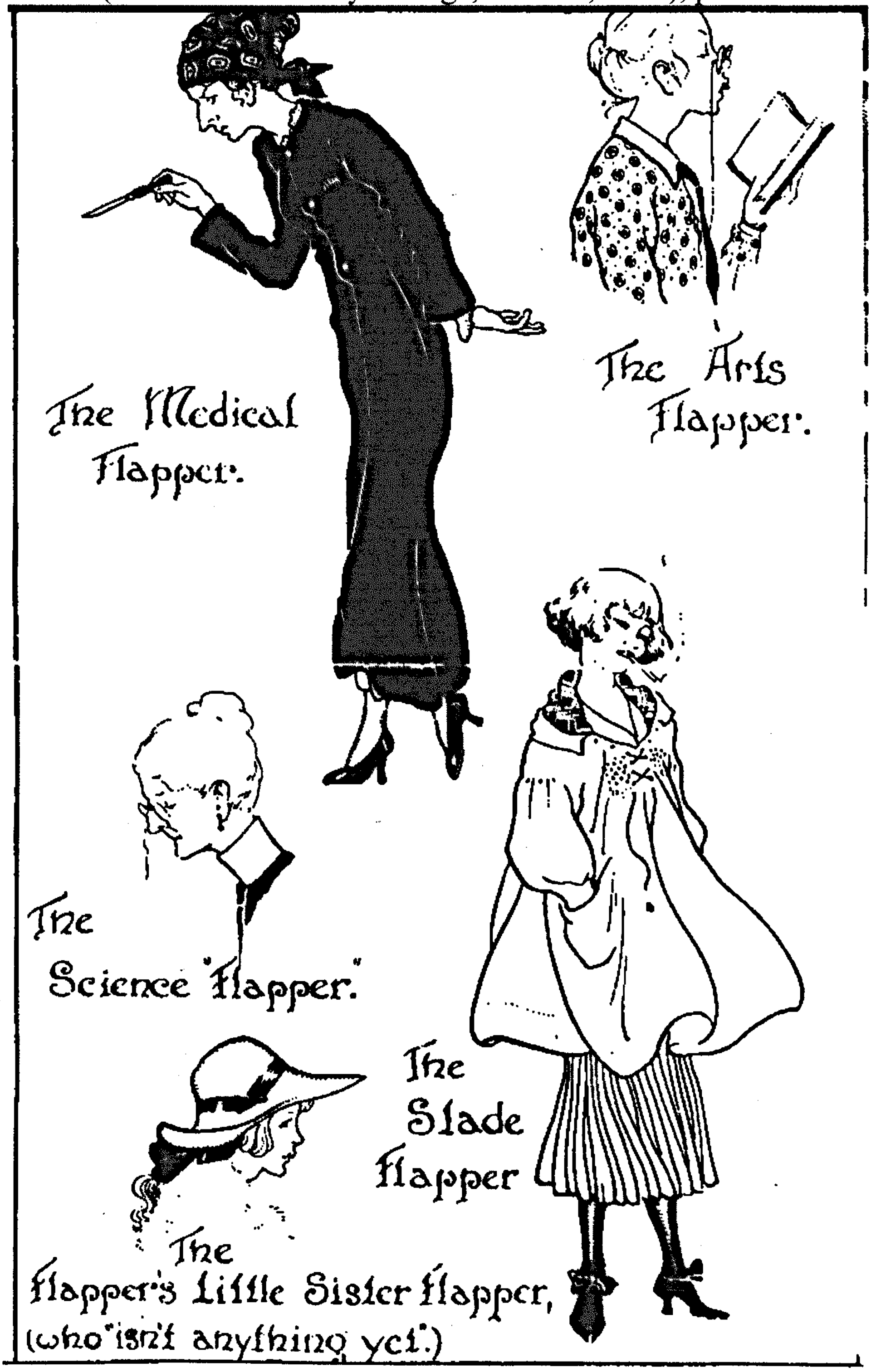


Figure 3.3
Reproduced from Negley Boyd Harte and John North, *The world of University College, London, 1828-1900, with an introduction by Lord Annon* (London: University College, London, 1979), p.143



Chapter four

The business of mathematics
Collaboration, reputation and Grace Chisholm Young

In 1911 William Henry Young, fellow of Peterhouse College Cambridge, part time mathematics coach and schools' examiner, applied for the chair of Pure Mathematics at Edinburgh University. His credentials were impressive. As well as experience in education, Young was a research mathematician with three books and ninety two original papers to his credit, a DSc from Cambridge and expertise in a new field of analysis that was having a profound impact on the development of mathematics on the Continent. Winning the Chair at Edinburgh was important to Young. During the last eight years he had failed to obtain chairs at Kings College London, Liverpool, Durham and Cambridge Universities and, having embarked on research mathematics at the relatively old age of thirty six (he was now approaching fifty) he was anxious that he should find a suitable post before he got much older. An examiner colleague of Young's, mathematician George M. Minchin of London University, wrote a testimonial emphasising his friend's exceptional reputation and extensive published work. In a private letter to Young he added:

> Perhaps I ought to have said that I was recommending the Firm of W.H.Young & Co. – for I by no means overlook the well-known name of the partner, CGY (Grace Chisholm Young) so well known to mathematicians.[1]

It was in no way remarkable that mathematicians should know Grace's name. Her success in gaining a first-class pass in the mathematics tripos while at Girton College Cambridge, and her subsequent doctorate awarded by the University of Göttingen in 1895, had given her some reputation in academic circles. Furthermore, it was claimed that Grace had been the first ever woman to achieve such a distinction in Germany; the fact that an English woman had succeeded in this way brought Grace transitory celebrity among the general population and in the national

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[1] LUSA, Young Papers, D140/9/146. George M. Minchin (1845-1914) had been a Professor of Mathematics at the Royal Indian Engineering College and the University of London; was elected a fellow of the Royal Society in 1895.

press. Despite Grace's relative prominence in her own time, like so many female mathematicians, her name rarely appears in histories of mathematics.[2] Even when remembered, her contributions to mathematics are invariably relegated to having provided a supporting role to her husband. An account of the Chisholm-Young partnership that has supplied source material for later authors recounts their relationship as a romance between a dutiful, loving wife and a man of (inevitably) disordered genius. She willingly dedicates herself to marshalling his creativity and performing the laborious tasks of writing-up and preparing his offerings for publication while he concerns himself with more important work. As Grattan-Guinness explains:

> ....an extraordinary reversal of roles took place... In 1896 the mathematical coach at Peterhouse married the young research mathematician of Girton and Göttingen, each presumably to preserve the same position in the partnership; but now it became clear that the coach had a far more profound and original mathematical mind .... and the young research mathematician, the catalyst who caused this profound change, became his secretary and assistant, perfectly capable of making original contributions of her own but basically needed to see that the flood of ideas that was poured out to her could actually be refined into rigorous theorems and results.[3]

Aims

In this chapter, the mathematical partnership of Grace Chisholm and William Henry Young will be analysed with a view to exploring the nature of their relationship and revealing the gender politics of their collaboration. It will be argued that Gratton-Gunness's account of the Youngs' collaboration presents a simplified narrative that reflects gendered assumptions about the nature of mathematical production and assumes that individuals are the sole unit of creativity. Teamwork cannot be incorporated easily within this romantic vision of the genesis of ideas and, if the partnership is a male-female one, the masculine configuration

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[2] A 1979 study showed that mathematical history books pay scant attention to female mathematicians and even contemporary female mathematicians had little awareness of their pioneering sisters. See introduction to Lynn H. Fox, Linda Brody, and Dianne Tobin, eds, *Women and the Mathematical Mystique: Proceedings of the eighth annual Hyman Blumberg symposium on research in early childhood education* (Baltimore: Johns Hopkins University Press, 1980), p. 14.

[3] I. Grattan-Guinness, 'A Mathematical Union: William Henry and Grace Chisholm Young', *Annals of Science,* 29 (2) (1972), 105-186, (pp. 140-141). Based on this account is Sylvia M. Wiegand, 'Grace Chisholm Young', in *Women in Mathematics*, ed. by Lynn M. Osen, (Cambridge, MA: MIT Press, 1990), pp. 247-253.

of 'genius' (upon which Gratton-Guinness's account is predicated) inevitably leads to the privileging of Young's role and the undervaluing of Grace. In consequence, Grace's support is acknowledged but presented as secondary and derivative upon her husband. Rather than being questioned by later scholars, this characterisation has often been reified and repeated.[4]

The best-known recent account of the Youngs' partnership is that provided by Sylvia Wiegand (who is a grand-daughter of the couple).[5] In an earlier short biography of Grace, Wiegand relied heavily on Grattan-Guinness for source material and, in large part, reasserted his gendered conclusions.[6] However her later, more detailed study provides a thought-provoking account of the Youngs' relationship allowing a more significant role for Grace as a 'creative mathematical thinker'.[7] Despite this, Wiegand is somewhat ambivalent as to whether the two were equal partners, or whether Grace was intellectually subordinate to her husband. Throughout her later article, Wiegand casts Grace in the role of 'assistant', describing how 'Grace threw her energy into assisting with Will's research so that he could concentrate on research ideas and "flood the journals" '; and how 'the Youngs' letters to each other give evidence of Grace's assistance to Will'.[8] Yet in conclusion Wiegand remarks that

> On the whole, since each other helped the other's career tremendously and their joint results were far better than the combination of what each could have achieved separately, it seems reasonable to consider them as equal partners.[9]

This ambiguity is a (perhaps unavoidable) reflection of the complexity and varying roles that Grace and her husband adopted within their collaborative relationship, something into which Wiegand offers suggestive insights which have been developed further here. This study differs from Wiegand's account in that it problematizes the Youngs' relationship and presents it 'warts and all'. As Grattan-Guinness before her, Wiegand presents an (understandably) romanticised account of her mathematical forebears; the following analysis suggests that Grace was not always 'more comfortable in emphasizing the family unit over her own identity' and that she and her husband were not always 'satisfied

[4] For example see Graham Sutton, 'The centenary of the birth of W.H.Young', *Mathematical Gazette*, 59 (1963), 17-21.
[5] Wiegand, 'Partnership of itinerant British mathematicians'.
[6] Wiegand, 'Grace Chisholm Young'.
[7] Wiegand, 'Partnership of itinerant British mathematicians', p. 126.
[8] Ibid., p. 130 and p. 135.
[9] Ibid., p. 138.

with their personal and professional lives and with the choices they had made'.[10]

To illustrate this, the politics of collaboration, and the gendered meanings that often attach to it, will be explored within the context of research mathematics. As discussed in the last chapter, recent scholarship in the history of science has successfully unravelled the notion of the lone, heroic investigator; in mathematics, however, such a conception has proved more tenacious. Here, emphasis on the individual intellect and neglect of context is indicative of the differences in material, philosophical and social practices between mathematics and experimental sciences. Hertha practised her profession in a very different material and epistemological setting from Grace and to include women mathematicians under the umbrella of 'women in science' is to obscure, rather than to reveal, important gender issues.

For Gratton-Guinness, the Youngs' relationship over the twenty years in which they were most active remains constant and unchanging. However a closer analysis reveals that their partnership was complex and dynamic, with each assuming varying roles at different times. Papers could be initiated by Grace, based on mathematics that she had pursued alone; at other times Young took the lead or suggested a problem which husband and wife then worked on together. Grace mentored Young in research mathematics at the beginning of their careers, assisted in the preparation of his lectures, and even instructed him in subjects in which he lacked the specialist expertise to teach. By a detailed look at the correspondence, mathematical notes and autobiographical accounts left by the couple, it will be demonstrated that to consider the Youngs as a 'family firm' is a useful way to characterise the partnership and make Grace's contribution visible. Once decided upon research mathematics as a business, 'the Firm' undertook market research and consulted Grace's eminent mathematical friends as to which area of mathematics would be most profitable. They underwent further training to bring their skills up-to-date and then decided business strategy. In order to secure a prestige academic appointment for Young, most of their product would be marketed under his name. That the vast majority of papers and one of their three books were published under Young's name alone does not imply that they were solely his vision and work. The Youngs used 'W.H. Young' almost like a modern company would use a brand; they felt

[10] Ibid., p. 139 and p. 140.

intense pressure to get their work into the mathematical market place before a competitor got there first and this made Young over-exacting in his demands and jealous of any time that Grace spent away from 'firm's business'. This model of mathematical research recognises that it is a social process in which inspiration and perspiration are inextricably combined. To suggest that Young produced the ideas and Grace the mathematical drudgery is to misrepresent the way their mathematics progressed. As Wiegand suggests, Grace colluded to an extent in losing her mathematical identity within that of her husband's, a finding that will be discussed with reference to other intellectual women who made similar choices. In the concluding section, the Youngs' mathematics will be assessed in relation to their elitist politics and philosophies and it will be suggested that both of these were rooted within the other. The focus of this chapter will be 1900–1916, the hectic years during which Grace and Young produced their most important work. But to understand the reasons why their partnership came about requires a consideration of the choices available to the two mathematicians in earlier years.

Mathematical options and personal choices

Grace Emily Chisholm arrived at Girton College at the start of the summer term 1889. She was funded by a small scholarship awarded by the College which was topped-up by an allowance from her father, senior civil servant Henry Chisholm, also a gifted mathematician. Grace idolised her father as a highly intelligent, affectionate man who introduced her to quadratic equations and mathematical modelling while her mother 'she supposed, was busy with household duties'.[11] Grace's first paper to the Girton Mathematical Club was on the complexities of her father's Department of Weights and Measures and she later dedicated her PhD dissertation to him. For Grace, her father represented an elision of rationality and status; these were both the antithesis of her mother's homely concerns and Grace, like others, made an early association between masculinity (her father) and abstract reason. In Virginia Woolf's *Night and Day*, the heroine Katharine Hilbery indulges a secret passion for mathematics as a retreat from the emotional complexities and womanly demands of female life into the contemplation of abstract symbols and geometrical figures.[12] For Grace

[11] LUSA, Tanner Papers, D599/16 and Young Papers, D140/12 (both are Grace's autobiographical notes).
[12] Genevieve Lloyd, *The Man of Reason: 'Male' and 'Female' in Western philosophy* (London: Methuen, 1984), p. 76.

too, the charm of mathematics resided in its impersonality, necessity, lack of ambiguity and removal from the contingencies of emotional and domestic life. As she wrote as a student at Göttingen to a friend threatening to visit, 'I fancy you would not like to be with me when I am working hard .... I become of necessity quite a different person from the me you know'.[13] In chapter one it was noted that Emily Davies, co-founder of Girton College, encouraged her women to take mathematics as this was (in the first two decades of Girton's existence at least) the most prestigious, 'manly' degree for men. However, that so many of her students complied may well be connected to the subject's aesthetic attractions as a welcome retreat from the prescriptions of femininity around 1900.

Despite her success in the mathematics tripos, the future was uncertain for Grace. For Young, being a wrangler had meant easy transition to a college fellowship and eligibility for mathematical coaching work. For Grace, no such opportunity was a real possibility. As a new college at a time when women's eligibility and aptitude for higher education was still a contested issue, Girton did not have the financial benefactors or resources to fund fellowships and lectureships in the same manner as the older, well-endowed men's colleges. In her personal notebooks, Grace criticises the female dons as being ineffectual and complains that all the main requirements for graduate study - scholarships, fellowships, position at university, the library and laboratories - were closed to women. This was not wholly true, although undoubtedly Grace felt that the obstacles preventing her pursuing graduate research or obtaining a teaching fellowship at Cambridge were overwhelming. A careers handbook for girls published in 1894 referred to the few teaching posts at the women's colleges at Cambridge and Oxford as poorly paid and chiefly attractive for the pleasant university life that they afforded.[14] For the instruction of 'undergraduates', the women's colleges relied mainly on young fellows from the male colleges and Girton (at least) could afford to pay them only a percentage of the fees that they received for teaching men. Nevertheless, these positions were sought after as Cambridge fellows, since the lifting of the celibacy restriction in 1882, often had wives to support and welcomed the extra income. There is some evidence that Grace was correct in implying that Girton's lecturers were, at times, inexperienced in the academic mores of Cambridge.

[13] LUSA, Young Papers, D140/6/44 (October 23 1893).
[14] Fernanda Perrone, 'Women academics in England, 1870-1930', *History of Universities*, 12 (1) (1993), 339-367 (p. 339).

Helena Swanwick recalled that in 1882 she had tried to engage the Mistress of Girton in discussion about her studies, but she had been less than helpful because 'she knew nothing whatever about the moral sciences (philosophy) tripos'.[15] Nevertheless, in the decades surrounding 1900 several notable female mathematics lecturers did take up teaching posts at Girton, as will be discussed in chapter six. However these opportunities were difficult to access, and even after Grace had achieved her doctorate there was little possibility of her being offered a staff position. Still, on her return from Göttingen, there was little to be lost from renewing useful acquaintances, so one of Grace's first acts was to send her published dissertation to her old Cambridge mathematical network, including William Henry Young.

In 1895 Grace's future husband was a man desperately seeking a calling that would justify the mathematical expectations placed upon him in his youth. His autobiographical notes suggest that he was tormented by a perceived failure to live up to his school-boy promise by achieving 'great things' at Cambridge – a failure that he blamed on the lack of room for 'creative mathematics' in an examination system geared to fiercely-competitive problem solving. Young had entered Peterhouse College with a scholarship in 1882, been disappointed to be placed only fourth wrangler, yet had gone on to gain a first in the part II examinations the following year. Since then he had been a part-time mathematical coach, investigated entering the legal profession, won a Peterhouse theological prize and engaged in a little experimental physics at the Cavendish Laboratory. Before taking up full-time residence in Cambridge in 1890, he taught at Charterhouse and other public schools and was an examiner at Eton. Grace first met Young when he became, very briefly, her replacement coach for a few weeks in her last term while her usual coach, Arthur Berry, visited Göttingen. The couple did not conform to the stereotypical relationship of male teacher/mentor and female student however. Young seems to have made little impact on Grace at the time; their daughter recalls that she viewed him as a 'mere boy.... needing help all the time he was supposed to be guiding her' and states conclusively that 'he did *not* tutor her'.[16] Despite this, the 'naturalness' of a woman taking such a subordinate role, and the ease with which this can

[15] Helena Swanwick, 'Memoir of Girton, 1882-1885', in *Strong-Minded Women and other lost voices from nineteenth-century England*, ed. by Janet Murray, (Harmondsworth: Penguin, 1992), pp. 239-242 (p. 240).

[16] LUSA, Young Papers, D140/2/2.1 (Cecily Tanner's notes on her parents. Tanner carried out the initial organisation of the Young archive which she gave to Liverpool University; later I. Grattan-Guinness, a Young family friend, continued her work.)

be extended to a stereotypical model of gendered collaboration, has meant that the myth that Grace was Young's pupil has persisted as a means to characterise their partnership. In a celebration of Young's centenary in 1963, Graham Sutton eulogises the 'great man' but makes only passing reference to his wife as having been one of his pupils, adding (with unfortunate implications) that Young had 'success with less than gifted pupils'.[17] More recently, Wiegand's essay on her grand parents has been placed in the category of 'Couples Beginning in Student-Instructor Relationships' in the edited collection within which it appears. This choice may have been editorial as the author herself gives a more complex account of the Youngs' collaboration which extends beyond such stereotypes. (In fact, Grace provided more tuition to Young, not the other way around, as will be demonstrated later in this chapter.) Grace had little to do with Young until after her return in triumph from Göttingen in the summer of 1895. Letters began between the two and soon Young was suggesting that they write a book on astronomy together (Grace had taken astronomy as a minor part of her doctorate). The nature of the collaboration that he envisaged soon became clear: he already had a body of notes prepared which required sorting for publication.[18] This project never materialised but correspondence continued, an engagement was arranged, and the couple married in June 1896. Grace was aged twenty eight years, her husband thirty two.

Sara Delamont has identified two available lifestyles for the graduates of the new institutions of higher education for women – the 'celibate career woman' and the 'learned wife'.[19] A degree enabled a lady to earn her own living in a new but respectable public role as schoolmistress, headmistress or don, maintaining impeccable moral standards in an all-female community. Although teaching was the preferred choice for the vast majority of female graduates, the women's colleges also had an important function in providing academics with suitable wives. Agnata Ramsey of Girton, who took the only first-class degree in classics in 1887, married the much older and widowed Master of Trinity, Henry Montague Butler. Newnamite Kitty Holt married one of her tutors, Cecil Whetham, and with him co-authored several books on eugenics.[20] Grace considered herself a mathematician, not a future teacher of mathematics,

[17] Sutton, p. 19.
[18] LUSA, Young Papers, D140/8/81 (courtship correspondence, Young to Grace, October (n.d.) 1895).
[19] Delamont, p.142.
[20] Barbara Caine, *Destined to be Wives: The sisters of Beatrice Webb* (Oxford: Clarendon Press, 1986), p. 141.

and fully expected to continue her research career while her husband pursued a conventional life as a Cambridge coach and don. Unlike the physical sciences, Grace needed no laboratory, apprentices or institutional position to engage in mathematics. She already had the qualifications, credibility and contacts. Although she had considered taking the same route as Charlotte Angas Scott and Isabel Maddison and had applied for a fellowship in the States, she was also concerned with women's duty to the family, so celibacy was not a determining factor in her application. Like other intellectual women such as Kitty Holt and her aunt Beatrice Webb, Grace had a fashionable interest in eugenics and admired the work of Francis Galton and Herbert Spencer. As she wrote in a telling phrase to a friend, '.....we are not improving the race by letting the best women remain unmarried because they are too exacting'.[21] However, in seeking to be a wife *and* a scholar, Grace was combining two occupations commonly held to be different and incompatible, roles which became increasingly polarised by the 1890s after some two decades of higher education for women. At this time, resentment of women who competed with men became more vociferous and was often felt particularly acutely by male dons' wives. Despite some women students acquiring Cambridge spouses, female scholars and wives increasingly came to be seen as fundamentally different kinds of women. 'Thus the two categories remained ideologically opposed, while some of the actual women involved were induced .... to regard one another with little confidence and sometimes little friendliness'.[22] It was tensions of identity such as these that may have contributed to Grace's decision to clothe most of her intellectual product in the name of W.H. Young.

William Henry Young

For Young, Grace must have seemed an attractive proposition. Not only could her reputation in Cambridge mathematical circles be of potential advantage and reflect on him, but her family connections could bring the social prestige that he always perceived that he lacked. (A sensitivity to his parents' status as successful grocers is a subtext in Young's autobiographical jottings). As a child in Haslemere, Grace had known the Tennysons and William Morris and her father had important

[21] LUSA, Young Papers, D140/6/60 (letter from Grace to Frances de Grasse Evans, (n.d.) c. 1893).
[22] Lidia Sciama, 'Ambivalence and dedication: Academic wives in Cambridge University, 1870-1970', in *The Incorporated Wife, ed. by* Hilary Callan and Shirley Ardener, (London: Croom Helm,1984), pp. 50-66 (p. 53).

government contacts. Shortly after their marriage, Grace lobbied her best friend's father, liberal MP Sir Francis Evans, to pull strings to secure Young's selection as chief examiner in mathematics for Wales. Despite this help, Young failed to secure the appointment. When the couple returned from honeymoon to Cambridge, both found life a little disappointing. Grace was bewildered by the social slights she was receiving from university neighbours and this may have been due to antagonism towards her husband whose self-importance and lack of empathy seems to have dogged him all his life. In 1919, while attempting to promote an international mathematical tour, Young contacted Harvard professor George Birkhoff in an effort to include his institution in the proposed itinerary. Birkhoff replied rather stiffly 'I am much interested in your analysis of our need for more intellectual cream. My analysis is somewhat different.'[23] Young perceived that Grace might have a useful role to play as a social intermediary; in a letter prior to their marriage he warns her that she must take care that his business letters containing complaints and the like are sufficiently diplomatic.[24]

Young's discontent with Cambridge, and the claustrophobic competitiveness of its politics, can be gleaned from his letters to Grace during his first prolonged absence from her in 1900. He describes himself as a 'fish out of water' and complains that 'the climate here unmans me .... (with) little knowledge and much jealousy'.[25] Young's use of the term 'unmans' is significant. In chapter two, the links between manliness and its manifestation in the production of 'great' mathematics which was (crucially) accepted as such by one's mathematical peers, was demonstrated with reference to Göttingen. At Cambridge too, mathematical genius was gendered acutely masculine and Young believed that he was falling short of this ideal. English universities were slow to accept the new, abstract style of mathematics that was represented by Göttingen analysis, and Young smarted at the lack of understanding or respect offered to his chosen specialist field. In addition, he believed that he was not receiving the support or opportunities at Cambridge that should be available to a man of his calibre. This was a time when reforms aimed at bringing mathematical teaching under the auspices of the University meant that demand from men's colleges for coaches was decreasing. With increased competition among coaches for students, fewer women from Newnham and Girton

[23] LUSA, Young Papers, D140/9/1 (Birkhoff toYoung, August 17 1919).
[24] Ibid., D140/8/201-9 (Young to Grace, April 27 1896).
[25] Ibid., D140/4/6 (Young to Grace, November 1901).

were requiring his services too; in addition he had been sidelined for an examinership which went to Grace's old coach Arthur Berry. Young interpreted his failure to succeed, plus the disempowerment that came with it, as an affront to his manhood. Historians of 'manliness' have emphasised that masculinity is a relational construct which, pre-1914, was informed by a man's reason, social power and privilege over the 'weaker' sex.[26] Young was keen to be independent of the 'whole lot of them' at Cambridge and this would only be achieved by gaining credibility as a successful mathematical researcher and author - something in which his wife was to play a crucial role.

Marriage and the beginnings of mathematical collaboration

The couple began their campaign to get Young's career on track early on in their marriage. Grace wrote to a friend emphasising how 'we must get Will's books written' if he was to achieve academic status and a professorship.[27] Earlier she reported that '.....there is so much to do, and however negligent I am of everything except 'the book' Will gets in a fever and talks of my many distractions'.[28] This was to be a recurrent theme throughout their partnership and became an even more pressing issue when the children were born, six between 1897 and 1908. The solution was 'girls' to look after the children and Young's unmarried sisters, Ethel and May, to supervise the household. Nevertheless, the pressure on Grace continued and was intense. Fifteen years later, Young's demands on his wife were no less intense with letters admonishing her for writing 'Oh Will', I have too much to do' and urging her to find a suitable girl to prevent the 'whole pack of cards' collapsing.[29] No wonder Grace surmised that Young would have been happy if he had been born Louis Quatorze.[30] Their daughter reminisced that the Young household ran on nervous energy with parents 'too high-pitched' to show affection - that was provided by 'Auntie May'.[31] When in 1900 the family took up permanent residence in Göttingen and Grace decided to consider medicine as a career to 'fall back on', Young veered

[26] 'Masculinity ..... is a relational construct, incomprehensible apart from the totality of gender relations', Roper and Tosh, p. 2; 'Masculinity is never fully possessed, but must perpetually be achieved, asserted and renegotiated', Kesiner, p. 15.
[27] LUSA, Young Papers, D140/6/179 (Grace to Frances de Grasse Evans, n.d., 1897).
[28] Ibid., D140/6/163 (Grace to Frances de Grasse Evans, August 24 1896).
[29] Ibid., D140/24/3 (Young to Grace, from Yokohama, October 1915).
[30] LUSA, Tanner Papers, D599/16 (Grace notebook).
[31] LUSA, Young Papers, D140/2/3 (Cecily Tanner's notes on parents).

between support and condemnation, urging her not to 'sacrifice your husband and your children to your medicine':

> My chance of getting any sort of position amongst jealous rivals like Berry and Whitehead is in any case small but of course it will be less if you take medicine and are therefore cut off from helping me...... If you decide on maths, and there is much to be said for it, then you will have to work hard at book writing while I am in Cambridge. Will you start on continuous groups say? Whether you decide on medicine or maths, and I naturally hope for my sake it will be the latter, you will have to arrange that the children do not interfere with your work.[32]

Grace acquired a Medical Students' Registration Certificate from London University and began her studies part time at Göttingen, culminating in a medical diploma in 1904. However mathematics displaced medicine as the 'Firm of W. H. Young & Co.' became securely established. Disenchanted with Cambridge, Grace and Young had left the city in 1897 for a first sojourn in Göttingen, prompted by conversations with Felix Klein, Grace's doctoral supervisor, who had visited Cambridge a few months earlier. Klein's (and Grace's) specialism of geometry was to be the Firm's first product area and in 1898 Young published three papers on this subject in the *Proceedings of the London Mathematical Society*. But to ensure that their mathematical skills were at the leading edge, Grace and Young needed further training. With their young son in tow, they travelled to Italy to study for a few months at Turin University with Professor Corrado Segre, a regular correspondent of Felix Klein, who was developing new ideas in the geometry of higher-dimensional space. They returned to Göttingen in late 1899 where they remained until a move to Geneva in 1908. Young was not a permanent resident abroad; in order to supplement the family's regular income from house leases, savings and investments, he returned for long periods to his job at Cambridge as a part-time coach and examiner. From 1905 Young also earned £100 per year as a special lecturer in mathematics at Liverpool University, six years later winning the title 'Associate Professor'. Despite their constant and prolonged separations, this permanent move to Göttingen heralded the start of the most productive period in Grace and Young's partnership.

[32] Ibid., D140/6/and D/140/4 (Series of letters between Young and Grace, October 1900).

Although husbands and male mentors/collaborators have been demonstrated to be one of the main vehicles of entry for women into science,[33] in the case of the Chisholm Youngs it was Grace, not Young, who primarily provided the contacts, secured opportunities for research and influenced the research agenda. As chapter six will describe, women encountered fewer obstacles in infiltrating mathematics as it did not necessarily require an institutional base. Hertha required a laboratory; Grace needed a pencil, a desk and, of course, access to a mathematical education. In addition, the world of pure mathematics comprised a relatively small community of individuals who knew (or at least knew *of*) each other. The most prestigious journals – in Germany *Crelle's Journal* and Klein's *Mathematische Annalen*, in England the *Proceedings of the London Mathematical Society* – were read and contributed to by a small and select international audience. Upon arrival in Göttingen, the couple were immediately a part of Grace's old mathematical network and they both made use of this to further Young's, and the Firm's, interests. Grace persuaded Klein, then one of the most respected names in mathematics, to write a testimonial for her husband. Klein was reluctant initially because, as Grace explained, '... he has hardly ever talked to you about mathematics..... and nearly all our mathematical communications with him have been carried on through me'.[34] Klein also commissioned Young to arrange an English language edition of his Encyclopaedia of Pure Mathematics. Young worked on this at Cambridge but found many of the Cambridge dons ambivalent to the project, in particular about his chief editorship; this prompted the Cambridge University Press to shelve their publishing plans. More significantly, it was Grace again, through her relationship with Klein, who set their business strategy a second time. Klein advised 'the Firm' to read Arthur Schönflies's[35] new work on set theory/functions, intimating that this was an important area of mathematics that was ripe for productive research – and he was right. Grace and her husband worked to advance this influential branch of mathematics for over two decades.

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[33] Pycior, p. x; Abir-am, p.8.
[34] LUSA, Young Papers, D140/6/499a (Grace to Young, November 1901. Grace writes that she will "drag a testimonial out of Klein, however unwilling he may be').
[35] Arthur Scönflies (1853-1928) had completed his doctorate with Klein at Göttingen and was then a professor of mathematics at Königsberg. He is known for his work in set theory and crystallography.

The theory of sets

Set theory, originating from ideas that Georg Cantor developed in the 1870s, presented what could be called, in Kuhnian terminology, a 'paradigm shift'. As one recent writer has described it: 'set theory opened up a gateway. It was as if you opened a door and on the other side of it was the surface of the Sun.'[36] Sets are at the foundation of modern mathematics because they are central to the way mathematical operations, from subtraction and addition to the logical processes of a computer, are conceived. A set is a group of things, usually having something in common. For example, an apple is in the set of apples, the set of fruit, and the set of objects that are spherical. Sets are also used to define the nature of number. The concept of infinity is intertwined with the theory of sets and it was Cantor who provided mathematicians with the means to use the concept of the infinite to make calculations. Set theory creates paradoxes; it generates multiple infinities (for example, the set of natural numbers is infinite but must be less than the set of real numbers, which includes all numbers including irrationals and transcendentals) and was logically undermined by Bertrand Russell.[37] Yet set theory's power means that, despite all this, it still retains its place at the heart of mathematics. Creating the rules to manipulate sets, creating the axioms (or fundamental assumptions) from which everything that can be known about a set can be deduced, and developing the logic and function theory (a function is a set of rules for turning one number or set into another) to enable mathematical operations, was the contribution of the Youngs to this new discipline.

Although the mathematical tools developed by Grace and her husband would be applied to physical problems (such as calculating velocity and problems in astronomy) their actual work was highly abstract and removed from particular everyday problems. William Henry Young's name is attached to the discovery, independently but around the same time as Henri Lebesgue, of the 'Lebesgue integral'. This solves the problem of defining the properties of shapes by reducing them to a set of

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[36] Brian Clegg, *Infinity: The quest to think the unthinkable* (London: Robinson, 2003), p. 157. This provides an accessible history of set theory and the concept of infinity.
[37] Russell's paradox is the most famous of the logical or set-theoretical paradoxes. The paradox arises within naive set theory by considering the set of all sets that are not members of themselves. Such a set appears to be a member of itself if and only if it is not a member of itself, hence the paradox: A. D. Irvine, "Russell's Paradox", in *The Stanford Encyclopedia of Philosophy (Summer 2004 Edition)*, ed. by Edward N. Zalta, <http://plato.stanford.edu/archives/sum2004/entries/russell-paradox/> [accessed February 12 2005]

points. The Youngs' 1906 book had as its title *The Theory of Sets of Points* and is seen as fundamental to introducing complex function theory to Cambridge. Through her experience and contact with Klein and his Göttingen school, Grace was instrumental in setting this research programme; she was also instrumental in its execution. The couple's extensive correspondence builds a vivid picture of the ways in which they collaborated. Grace's role can be identified as maintaining 'the Firm's' up-to-date mathematical expertise from her base in Göttingen; engaging in 'mathematical networking'; using her greater technical skills to hone papers and ensure accurate proofs; contributing ideas and research developed alone; and writing up the papers (her own, her husband's and papers published under both names). Grace also supported Young in his teaching by researching lecture material, assisting in marking, and providing him with coaching when he was required to teach subjects beyond his experience.

The Youngs' partnership deconstructed

In 1902, Young writes from Cambridge of his annoyance that he has not been asked to examine for part II of the tripos because he 'doesn't know functions' and asks Grace to explain Schönflies's oscillating functions to him.[38] This was a typical pattern for the couple from around 1900 to 1908. Grace, based in Göttingen where research was being originated, was able to ensure that Young stayed up to date with developments even though he was far away in Cambridge. She attended regular 'colloquiums' or weekly seminars with the professors at her old university and frequently reported the mathematical news and views of Klein, Hilbert and the others with whom she maintained social, as well as academic, relations. This was performed knowingly and was not merely incidental. Grace sends Young her notes from these events and responds to her husband's urging to obtain from Klein, and critique herself, pre-publication proofs of other mathematicians' work (including Schönflies's). In 1903 she copies out a paper of Henri Lebesgue for him, warning that it is 'hard to understand', and sends him an example of a theorem 'which you and I have been hammering at for so long'.[39] Grace also 'sounds out' Klein about possible papers for Young to publish: 'The impression left on my mind was that a good lucid exposition of the

[38] LUSA, Young Papers, D140/4/1 (Young to Grace, September 22 1901). Between 1909 and 1911 William Young carried out a long-running dispute with Schönflies on the pages of the *Messenger of Mathematics*.
[39] LUSA, Young Papers, D140/30/1-2 (n.d., from Youngs' correspondence on mathematics, 1891-1914).

subject would meet with his approval, though you understand, I hinted at nothing.[40]

There is no doubt that 'the Firm' relied on Grace to maintain high levels of quality assurance for their product. Their correspondence is littered with requests to Grace to check his (and his rivals') reasoning and find flaws, and Young sends her copies of theorems that he is having difficulty proving. In 1903 Young writes of a stubborn problem on the upper integral and his pleasure that Grace can work it out further for him (his paper on the subject appeared the following year).[41] As late as 1914 Grace points out to her husband that a theorem of his published in the *Proceedings of the Cambridge Philosophical Society* in 1910 was untenable, noting that at the time they had both believed that it had 'come out too easily'. She then outlines the fallacy and rectifies the problem.[42] Grace did not take a passive role in the mathematical partnership and would often take the lead, for example by withdrawing papers when Young wanted to publish too early. In January 1906 Grace is peremptory in ordering her husband to withdraw one of his papers due to errors:

> The fact is the <u>definition</u> won't do: with your definition, as it stands, we do not necessarily get, in the case of an ordinary function defined for a segment, the 'upper integral' in the old sense, at all. Secondly, with your definition, as it stands, the theorem upper integral = upper integral of associated upper is not true. See the following example...[43]

The combined contributions of Grace and her husband blur any easy distinction between 'ideas' and 'technical execution'. There are numerous examples of Grace suggesting the subject matter of a paper and her diary entries show how she worked hard at developing new techniques and not just solving problems. In 1912 Grace writes of grappling to find a new method to apply to Fourier series, noting '.... working at multiple Fourier series all day, got it all finished by 11.30pm'.[44] This was a subject upon which Young published several well-received papers in the *Proceedings of the London Mathematical Society* between 1910 and 1916.

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[40] Ibid., D140/6/357 (Grace to Young, October 22nd 1900).
[41] Ibid., D140/30/1 (Young to Grace, February 1904): W.H. Young, 'On upper and lower integration'. *Proceedings of the London Mathematical Society*, 2, (1904-5), 52-66.
[42] LUSA, Young Papers, D140/24/2 (Grace to Young, March 5 1914).
[43] Ibid., D140/7/1.20 (Grace to Young, January 1906).
[44] Ibid., D140/5/1 (Grace's diary 1908-1939).

Gratton-Guinness credits Grace with the 'writing-out' of her husband's papers, turning his creative ideas into lucid text. Certainly Grace contributed enormously to the intelligibility of Young's papers and managed all the administrative labours connected with proof reading and publication. When Grace ceased work in despair at the death of her eldest son in 1917, letters begin appearing from G. H. Hardy, Young's main referee for the *London Mathematical Society*, questioning Young's 'diffuse' writing and 'untidy, inconsistent referencing'.[45] However the couple also worked the other way around and it is too simplistic, given the high level of expertise of both, to assume that their roles did not change and overlap. For example, at times Young sends Grace problems for which he needs solutions on the understanding that, once he receives her answers, he will write out the papers himself.

Young held various teaching and examining positions during this time and relied on Grace to provide support for this too. In 1901 she helped him mark Cambridge's 'Little Go' papers and planned a course on geometry for him. When Young was finally appointed to the Central Welsh Examinations Board in 1902-5, Grace translated past papers into German and arranged for her German mathematical friends to evaluate them. When in 1913 he was appointed to an Associate Professorship in the History and Philosophy of Mathematics at Liverpool University, Grace commenced studies in philosophy, corresponded with Bertrand Russell, and reported to her husband that she had 'matter enough for a whole course of lectures for you'.[46] Given the extent of Grace's contribution to the 'Firm of W. H. Young & Co.', it is difficult to see how her role could be reduced to that of mere secretary and assistant. Certainly in one letter to her mother (one from which Gratton-Guinness quotes)[47] Grace writes of how exciting her husband's papers are and how she helps him 'as secretary and critic a little'.[48] However Grace was keen to build up Young's prestige to a family who did not like him and who were hostile to the couple's move away from England. Grace's marriage heralded a rift with her parents, especially her mother, which lasted until they died in the early 1900s. Simultaneously as she wrote to her mother, Grace takes joint ownership of her husband's papers in a letter to a close

[45] Ibid., D140/9/47 and 49 (Hardy to Young, n.d. c.1917/18). G.H. Hardy (1877-1947) was an analyst and professor of mathematics at Cambridge, in 1919 he left that University to take up the Savilian Chair at Oxford . Young's lack of brevity in his papers was exacerbated by a paper shortage that became acute during WW1.

[46] Ibid., D140/24/2 (Grace to Young, February 27 1914).

[47] Grattan-Guinness, 'Mathematical Union', p. 136.

[48] LUSA, Young Papers, D140/6/228 (Grace to mother, June 1898).

friend by explaining that 'We are getting on with the mathematics, have finished the second paper, which was hard work, and have got a good deal of the third down'.[49] Assigning to Grace the role of directed labour, performing the routine mathematical tasks that freed Young to use his genius unencumbered by detail, is in keeping with a gendered assignment of duties, reflected in later historiography. Recent scholars have shown how women were inevitably assigned the role of 'assistant' in both-sex collaborations, whatever the nature of their individual contributions.[50]

Another celebrated mathematical research partnership, active at around the same time as the Youngs, is that of Oxbridge professors G. H. Hardy and J. E. Littlewood. Hardy and Littlewood, who collaborated for thirty five years from 1911, were analysts like the Youngs and have been credited with creating a school of mathematical analysis at Cambridge.[51] In historical accounts of their work a similar division of roles is assigned to their male partnership as has been assigned to the Youngs:

> (Hardy's).... long collaboration with Littlewood produced mathematics of the highest quality. It was a collaboration in which Hardy acknowledged Littlewood's greater technical mathematical skills, but at the same time Hardy brought great talents of mathematical insight and a great ability to write their work up in papers with great clarity.[52]

Despite this division of labour, the Hardy-Littlewood partnership has not been forced into conformity with a model of 'genius and assistant', quite the reverse. A recent work of scholarship describes their collaboration as the 'most remarkable and successful partnership in mathematical history.... these giants produced around one hundred joint papers.....'. Littlewood's role is described as making the 'logical skeleton, in shorthand' while Hardy's contribution was to provide proofs and write up joint papers. Despite this, here and elsewhere, they have both been characterised as mathematical geniuses. In this account, far from 'writing up' being presented as a mundane, derivative task, when Hardy performs the role he is represented as 'the consummate craftsman, a connoisseur of

[49] Ibid., D140/6/224 (Grace to Frances de Grasse Evans, June (n.d.) 1898).

[50] For example: Margaret W. Rossiter, 'The Matthew /Matilda effect in science', *Social Studies of Science*, 23 (1993), 325-341; Sime, pp. 326-329, documents how Lise Meitner was overlooked for a Nobel Prize for her contribution to the discovery of nuclear fission; the prize went to her male partner Otto Hahn despite Meitner being the lead investigator.

[51] Robin J. Wilson, 'Hardy and Littlewood', in *Cambridge Scientific Minds*, ed. by Peter Harmant and Simon Mitton, (Cambridge: Cambridge University Press, 2002), pp. 202-219 (p. 202).

[52] John J. O'Connor and Edmund F. Robertson, 'G.H. Hardy', in *The MacTutor history of mathematics archive*, <http://www-history.mcs.st-andrews.ac.uk/history/index.html> [accessed February 5 2005]

beautiful mathematical patterns and a master of stylish writing'.[53] In this all-male partnership, the 'technical skills' of one collaborator have not been used to downgrade his contribution to work produced jointly; 'technical' aptitude and a flair for 'writing up' tends to be undervalued only when a gender dimension is added. The above description of the Hardy-Littlewood collaboration, as well as the example of the Youngs, problematises perceptions of mathematical research that rigidly distinguish between 'ideas' and 'technique' and assign the former to individual intellects alone. It is difficult to separate the two or to give one a privileged position in the development of mathematics. Collaboration is common in mathematical research, despite the persistence of 'lone-genius' mythology, and Hardy and Littlewood both had other collaborators besides each other.

Of course, Hardy and Littlewood published their papers under joint names; this was not often the case with Grace and her husband. The publishing strategy of the 'Firm of W.H. Young & Co.' was to achieve prestige and position for Young, and they needed them quickly to secure their financial situation. It would have been difficult to earn a living solely by writing, advances were rare and most contracts stipulated a fixed fee for receipt of work. Rewards were not high and most male authors combined writing with another career. When Young attempted to publish Klein's encyclopaedia in English he had to approach the London Mathematical Society and the Royal Society for funding; when the Cambridge University Press finally turned down the project, Macmillan Publishers suggested trial runs of small volumes retailing at just one shilling each. Grace published only four papers under her name alone (including her PhD dissertation) up to 1905; she resumed in earnest in 1914[54] after Young was appointed to an associate chair at Liverpool University and, shortly after, Calcutta University. Grace's later work included an important series of papers on the foundations of differential calculus, one of which won the Cambridge Gamble Prize in 1915. Up to 1914 Young published approximately eighty eight papers. Six papers were published jointly and it is difficult to see why Grace and her husband broke their publishing routine in these cases. Possibly one was published in both names because it was for an Italian journal, the others because Grace had done the majority of the research: one of these papers is on derivates which was a subject upon which she concentrated from 1914 onwards. Three books appeared during this time too, two (*A First*

[53] Wilson, 'Hardy and Littlewood', pp. 202-205.
[54] Grace published one paper in 1912.

Book of Geometry, 1905, and *The Theory of Sets of Points*, 1906) were published in joint names, the other (*The Fundamental Theorems of the Differential Calculus*, 1910) in Young's name alone. It is possible that *A First Book of Geometry* was written solely by Grace. It was published in her name alone in the German edition and correspondence suggests that it was indeed her project. Certainly this was a basic school textbook and therefore within the remit of women authors who were channelled into writing for children or educated laypeople. When publishing for a more scholarly audience, it was harder for women to establish their credibility. Grace describes in letters and her diary how she designed paper models and drawings for the geometry book with her young son; this was an activity which she had loved to do with her father as a child.

Division of 'the laurels'

In a 1902 letter marking the start of the most productive years of their collaboration, Young outlines his programme for the couple and their publishing aims:

> I hope you enjoy this working for me. On the whole I think it is at present at any rate quite as it should be, seeing that we are responsible only to ourselves as to the division of the laurels. The work is not of a character to cause conflicting claims. I am very happy that you are getting on with the ideas. I feel partly as if I were teaching you, and setting you problems which I could not quite do myself but would coach you to. Then again, I think of myself as like Klein furnishing the steam required – the initiative, the guidance. But I feel confident too that we are rising <u>together</u> to new heights. You do need a good deal of criticism when you are at your best, and in your best working vein. The fact is that our papers ought to be published under our joint names, but if this were done neither of us get the benefit of it. No. Mine the laurels now and the knowledge. Yours the knowledge only. Do you suppose people will venture to say the laurels ought to be yours? No, they would be very unwilling to allow that ..... divide and we are lost. Everything under my name now, and later when the loaves and fishes are no more procurable in that way, everything, or much, under your name. There is my programme. At present you cannot undertake a public career. You have your children.[55]

[55] LUSA, Young Papers, D140/6/553 (Young to Grace, February 15th 1902).

Grattan-Guinness quotes this letter but does not recognise that it alone may question his assignment to Grace of a merely secondary role.[56] Interestingly, he quotes the entire section as above with only one omission – the passage where Young seems to be anticipating a protest by Grace: 'Do you suppose people will venture to say the laurels ought to be yours? No, they would be very unwilling to allow that ....' This version, with the same omission, is repeated again (quoted from Gratton-Guinness) in Wiegand's article,[57] although the quotation is used in full in another short biographic account of the Youngs by Patricia Rothman.[58] Young's 'missing' words could be interpreted as a warning to Grace. Is her husband asserting that people would not accept that a woman had done the work? More likely, Young is implying that people would frown on a wife who took credit away from her husband; antipathy to women's intellect was especially strong when it rivalled *publicly* the intellect of men. This was one of the arguments put forward by opponents of higher education for women who urged complementarity between the sexes, fearing that 'unnatural' competition would be the result if men and women were to operate in the same sphere. This stricture was even more compelling when the individuals concerned were man and wife, as wifely duties required being a support to one's husband, not a rival. In fact, being a rival to one's husband could be interpreted as competing against yourself: a man and his wife were regarded as 'one' by sections of society opinion and by the law[59] and this could impact on women seeking an independent identity. When Hertha Ayrton sought election to the Royal Society it was refused (nominally at least) on the grounds that as a married woman her person was included in that of her husband and, therefore, she was ineligible for consideration (her husband, William Ayrton, was already a fellow).

It will be argued below that although, to a large extent, Grace acquiesced in absorbing her mathematical identity into that of her husband's, at times she also rebelled against it. Despite Young's admission that papers should really be published under both their names, in practice he was very careful, in any public context at least, to exert his superiority. For

[56] Gratton-Guinness, 'Mathematical Union', p.141.
[57] Wiegand, 'Partnership of itinerant British mathematicians ', p. 137.
[58] Patricia Rothman, 'Grace Chisholm Young and the Division of the Laurels', *Notes and Records of the Royal Society of London*, 50 (1) (1996), 89-100 (p. 94).
[59] Women's rights campaigners in England had been working since the mid-nineteenth century to secure rights for married women, in 1882 their lobbying brought some success with the 'Married Woman's Property' Act which allowed women to retain their own property on marriage, but their person was still included within that of their husbands in other areas and, of course, women did not have the vote.

example, in the preface to their 1906 book, to which Grace contributed at least equally to her husband, Young writes

> Any reference to the constant assistance which I have received during my work from my wife is superfluous, since, with the consent of the Syndics of the Press, her name has been associated with mine on the title-page.[60]

Young hoped that a good reception for his book would lead to him being offered a professorship and he did not want his recognition diluted by being shared with his wife - a woman who had already acquired a mathematical reputation and who was well-known in mathematical circles for her success at Göttingen.[61] The same concerns are discernable on the pages of the *Proceedings of the London Mathematical Society* which was an important outlet for the Youngs' papers. Young is careful to maintain his dominance in this mathematical journal; for example, in the volume in which Grace's name first appears as co-author of a joint paper with her husband, Young also publishes four papers under his name alone. This was typical and Young was a highly-active contributor to the *Proceedings* in the first decade of the twentieth century, publishing up to seven papers each year (while simultaneously holding down a full-time job). Such was Young's productivity during this time that it is noted in more than one memoir as exceptional and in need of explanation. For Sutton, Young's life is a 'great enigma': it is 'an extraordinary thing that a man should spend so much time on the hack work of coaching and then suddenly spring into prominence as one of the most prolific and greatest analysts of his time'.[62] Like Sutton, Hardy refers to Young's late start but notes 'the productivity, when it did come, was so astonishing' and adds that 'the dreams were to come and the 'drudgery' to end, and the end came quickly after Young's marriage'.[63]

There is no doubt that Young benefited the more from their collaboration. He was awarded a DSc from Cambridge in 1907 on the basis of his published papers and in the same year was elected a fellow of the Royal Society. In 1913 he was appointed Associate Professor at

[60] W.H. Young and Grace Chisholm Young, p. vi.

[61] Rothman recounts an amusing anecdote (received from a friend of the Youngs, A.S. Besicovitch) which illustrates Young's insecurity: 'William Henry Young was out swimming one day with Besicovitch and he got into difficulties. Besicovitch swam over to help him. With Besicovitch's assistance, W.H. Young came up for a "third time" coughing, his long beard bobbing in the waves, he spluttered out as he gasped for breath "Are you one of those people who think my wife is a better mathematician than I am?" ', Rothman, p. 97.

[62] Sutton, p. 21.

[63] LUSA, Young Papers, D140/30/5.1 (G.H. Hardy, 'W.H. Young', *Journal of the London Mathematical Society*, 17 (1942), 218-237 (p.220).

Liverpool University, a few months later the first Hardinge Professor of Mathematics at Calcutta University, and in 1919 Professor of Pure Mathematics at the University of Wales at Aberystwyth. The London Mathematical Society awarded him the De Morgan Medal in 1917 and the Royal Society awarded him its Sylvester Medal in 1928; in the same year he was elected an honorary doctor at Strasbourg University. Young served as President of the London Mathematical Society 1921-25 and in 1929 was appointed President of the International Mathematical Union. Three years before he died he was elected to an honorary fellowship at his old Cambridge College, Peterhouse. Grace and Young's story highlights the futility of looking to male frameworks of achievement in order to establish women's participation in mathematics or science. An examination of published papers, scientific awards and prestigious appointments will throw light only on Young's career; Grace's achievements will remain in the shade. To render women's contributions visible it is important to look beyond the public sphere. As one historian has suggested, the unbalanced gender structure of modern science may result 'not so much from the exclusion of women from science, but rather from the exclusion of the *domestic* realm from science, and the incidental concomitant exclusion of women'.[64]

Intellectual women and 'womanly' roles

Grace has been represented as a dutiful, self-sacrificing wife who willingly used her mathematical skills to aid her husband and further his career. Although this is partly true, the complete picture is more complex. Certainly Grace felt that she and her husband were working in partnership for the firm of 'W.H. Young & Co.'. She is quoted as preferring to remain 'incognito to the outside world.... husband and wife being one' and fearful of being seen as 'ambitious for herself and her own glorification'.[65] Grace was anxious, especially during the first few years of her marriage, that she was failing in her role of 'helpmeet' to her husband. Indifferent to women's suffrage, part of her adhered to a Ruskinesque ideal of women as supporters and enablers of men that was an influential belief, endorsed by the new Darwinian sciences, which persisted to the first years of the twentieth century. Grace's academic background may have contributed to, rather than questioned, such ideas. Carol Dyhouse has suggested that in some ways the new educational institutions like Girton functioned as conservative establishments

[64] Abir-am, pp.3-4.
[65] Wiegand, 'Partnership of itinerant British mathematicians', p. 140.

fostering conventional values and ideals about femininity and female service.[66] A common allusion in the Youngs' correspondence is an admiration for the Brownings; Grace was an admirer from childhood of Elizabeth Barrett Browning's novel-poem, *Aurora Leigh.* This epic was very popular and had passed through five editions by the time Barrett Browning died in 1861. Deirdre David has demonstrated how, within the poem, women's intellectual product is made the servitor of male cultural authority, reflecting Barrett Browning's belief in the ultimate superiority of men's minds and the 'yearning' that women have to 'lose ourselves' in male partners. David's conclusion that in the poem we hear a woman's voice speaking patriarchal discourse – boldly, passionately and without rancour – is to some extent descriptive of Grace.[67]

Grace's autobiography is a romanticised account of her Girton years along the lines of L.T. Meade's popular novels of the time about the fictitious women's college 'Merton'.[68] Written with hindsight, in the third person and with names changed, Grace portrays herself as a tall, slender Girtonian called Iris while Young is turned into a 'Darcy-like' hero called Mr King whose ridicule reduces his female students to tears.[69] To use this material uncritically, as Grattan-Guinness has done, is to ignore the tensions that clearly emerge in Grace's letters, diaries and notes. Despite acquiescence to her husband, Grace's desire for recognition did not always lie quiet and Young was not above pressing his claims on her time and intellectual product. In one of Grace's notebooks she pens some personal thoughts amongst the mathematical jottings, including her concern that Young says people 'despise her' plus this silent 'answering back':

> Will said to me today 'A woman ought not to mind playing second fiddle, it is not really such a hardship. Women play second fiddle far more satisfactorily. Think of Mrs Browning. If instead of working in separate rooms at their separate poems, she had thrown herself with Browning's work and helped him to express himself more clearly and exactly, and think more conscientiously, his work would have been infinitely better, and a great deal of her stuff

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[66] Carol Dyhouse, *Girls growing up in late Victorian and Edwardian England* (London: Routledge and Kegan Paul, 1981), p. 172.

[67] Deirdre David, ' "Art's a service": Social wound, sexual politics and Aurora Leigh', in *Victorian Woman Poets: Emily Brontë, Elizabeth Barrett Browning, Christina Rossetti,* ed. by Joseph Bristow (Basinstoke, Macmillan, 1995) , pp. 108-131 (p. 129).

[68] For a discussion of the work of L.T. Meade see Garriock, pp. 196-255; for a discussion of 'The Girton Girl: Social Images from within and without', see Bradbrook, pp. 91-112.

[69] LUSA, Young Papers, D140/12/22 and 23.

would never have been published. She may have published two or three really good things herself and nothing lost.[70]

Grace suffered a particular bout of depression around New Year 1900 when she wrote, in tears to a close friend, that all of her hopes for her future, by which she meant her mathematical ambitions, were disappearing.[71] Her friend, who had been a fellow student at Girton, emphasised ideals of female service in her reply and advised that she could not think mathematics 'a duty higher than one's duty to one's family'.[72] It is significant that as soon as her husband had secured a worthwhile position Grace resumed her own publications.

For most of their married life, Young was absent from the home for long periods of time. He maintained rooms at Peterhouse College and so remained to a large extent in a masculine, manly environment where femininity rarely infiltrated. To colleagues he implied that he preferred to be separated from his family during the working period.[73] Nevertheless, he liked to assert his authority over the household and insisted on being informed of the smallest detail, controlled the children's daily schedules and even obliged Grace to send him her accounts. In 1871 Samuel Smiles wrote that it is in the home that 'a man's real character ...his manliness is displayed'. Young can be aligned within a later-Victorian concept of manhood in which masculinity is never fully achieved but has to be constantly asserted and renegotiated. John Tosh has warned that the notion of 'separate spheres' can be misleading in suggesting a true complementarity in which each spouse is sovereign in his or her domain. He suggests that men, especially those engaged in sedentary, 'feminised' intellectual work, required a forceful assertion of will over wife and home to realise their masculinity.[74] Unlike Hertha's husband, who was secure in the gendered, masculine codes of his profession, Young felt the need to assert his masculinity more explicitly. After the estrangement and later death of Grace's father in 1901, Young took to himself the roles of both husband and father.[75] This double dose of Victorian patriarchy dominated Grace in her role as mathematician, as well as in her roles as wife – and 'daughter'.

[70] LUSA, Tanner Papers, D599/16 (Grace's notebook, entry dated '25.V.17').
[71] LUSA, Young Papers, D140/6/328 (Grace to Frances de Grasse Evans, December 30 1899).
[72] Ibid., D140/6/329 (Frances de Grasse Evans to Grace, January 7, 1900).
[73] Ibid., D140/9 (Young to P. Dienes, (n.d.) 1921).
[74] Tosh, pp. 44-73.
[75] LUSA, Young Papers, D140/24/2 (Young to Grace, January 16 1901: 'I will try and fill a father's as well as a husband's place to you').

In the late Victorian/Edwardian era literary images of scientific and learned women were used in books and girls' periodicals to instil ideals of service and teach moral lessons. Mathematician Mary Somerville was commonly represented as an ideal of learned femininity for selflessly dedicating her life to bringing the astronomical writings of Laplace to an English audience.[76] Eleanor Sidgwick was represented and praised by her niece for having 'silently renounced' study for the Cambridge mathematics tripos in favour of supporting her husband and his work.[77] Paula Gould has uncovered some compelling examples of this and argues that the construction of scientific heroines as assistants, companions and directed labour should be read as a strategy for preserving prevailing gender hierarchies within the developing context of science. Her example comes from an 1897 *Lady's Realm* short story 'An Admirable Arrangement': A Cambridge don is dismayed that the Girton graduate who is fellow guest at a house party has done original research and produced a theory to rival seriously his own, jeopardising his academic reputation. The narrative is resolved by the two falling in love, with the girl promising to marry the don on condition that he include her work in his next book, putting only his name on the cover.[78] Grace can be aligned, in part, with other intellectual women who absorbed this moral message, shunned public recognition, and submerged their talents to further the interests of male relations. Margaret Huggins took a pivotal role in research with her celebrated husband, astronomer and President of the Royal Society William Huggins, whom she married in 1871. Margaret brought her own photographic expertise to the partnership, developed new techniques of research and carried out much of it herself. Despite this, Barbara Becker has demonstrated how the couple colluded to present a traditional and romanticised image of themselves with William as the principal investigator and Margaret as his able assistant.[79] Barbara Caine in her book on Beatrice Webb and her sisters reaches similar conclusions as to the limited nature of many women's ambitions, despite the changes of the late-nineteenth century. For the 'Potter girls' public activity provided a way of supporting and assisting husbands; even Beatrice who, like Grace, had already made a mark in her chosen path, dedicated two thirds

[76] Neeley, pp. 206-214.
[77] Sidgwick, 'Mrs Henry Sidgwick', p. 66.
[78] Paula Gould, *Femininity and physical science in Britain 1870-1914*, (unpublished doctoral thesis, University of Cambridge, 1998), pp. 202-207.
[79] Becker, pp. 98-111.

of her career while married to furthering her husband's work and political ambitions.[80]

Conclusion

Despite her partial acquiescence to submerging her mathematical identity with that of her husband, Grace can be interpreted as a 'feminist'[81] although she did not support the suffrage cause and spoke against it at a college debate in her first year at Girton. Recent scholarship on 'the new woman', commonly linked with 'graduates' from the new women's colleges, has problematised the one-dimensional portrayal of this figure as one who privileged independence over family and rejected sexual difference or differing social roles based on biology.[82] Eugenic feminism was a strong thread in Edwardian Britain, predicated on woman's role as mother, and Grace exhibited strong sympathies with this; she admired the novels of Sarah Grand[83] and, as outlined in chapter two, wrote a personal handbook for girls and their guardians which explicitly endorsed such views. As indicated in chapter two, Grace's pure mathematics which assumed a natural aristocracy of intellectual talent, by necessity gifted to just a select few, was easily associated by her with an eugenics that privileged inherited intellect. The Youngs' mathematics also informed, and was in turn informed by, an elitist, even coercive, politics that developed in later years to criticise wider access to education as 'rewarding memory at the expense of intellect' and to describe socialism as a 'monstrous doctrine promulgated by the commercial classes'. This flight to exclusive extremism was made with direct reference to the growth of the practical sciences and their (relative) democratisation of access (to men) based on acquired skill and meritocratic principles. In an unpublished article headed 'Bureaucracy and Intellect at Cambridge and the Royal Society', Young rails against the devaluation of 'intellect' at these institutions and argues that within

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[80] Caine, pp.181-197.

[81] 'Feminist' would not, however, have been a term that Grace would have been likely to apply to herself. Its origin is commonly attributed to early-nineteenth century France and the earliest reference found to its usage in English is in an article in the *Westminster Review* in 1898. See Delap, 'Philosophical vacuity and political ineptitude', p. 626.

[82] Angelique Richardson, *Love and Eugenics in the late nineteenth century: Rational reproduction and the new woman* (Oxford: Oxford University Press, 2003), p. 8. See also Sally Ledger, 'The New Woman and the crisis of Victorianism', in Ledger and McCracken, pp. 22-44.

[83] Sarah Grand (1854-1943) combined commitment to women's emancipation with a belief in biological determinism and eugenics. While at Girton, Grace was influenced by Grand's 1893 book *The Heavenly Twins* in which a 'highly-bred' woman is married to a man of loose morals; the novel's themes are venereal disease, social purity and the consequent withholding of sexual favours by women. For a discussion of Grand's *The Heavenly Twins*, see Ledger, 'The New Woman', pp.32-35.

'our modern civilisation .... every science is one-sided to the extreme, so much so as to be almost vulgar. Each science has come to be the occupation of inferior minds'. Again, the emphasis is on individual minds - special intellects which the natural elite are born with and which can be acquired in no other way. In the 1930s, both Grace and her husband flirted with fascism as 'competition between races becomes inevitable when there are inferior types' and Young entered into correspondence with Mussolini and Oswald Mosely.[84]

To recognise Grace's mathematical contributions is not to downgrade her husband's achievements; an exploration of the tensions within their partnership is not a denial of the existence of genuine affection between the two. To see beyond the standard narrative of strong, intellectual manhood and selfless, secondary womanhood, is a start in unlocking the complexities that these hierarchies hide. It is only in so doing that the major misrepresentation and under representation of women in mathematics and science can be fully understood. Yet, as illustrated in the previous chapter, any woman seeking to step outside this narrative confronted obstacles that women who negotiated their mathematical or scientific identities within the stereotypical ideals of 'feminine service' did not meet. Hertha repudiated these stereotypes, argued for equality between the sexes and refused to be placed on a pedestal. Grace came to believe in a special role for women and predicated her feminism on the 'difference' of the female sex. Yet, whether they embraced 'new' or 'traditional' attitudes to a 'woman's place', they both encountered problems in reconciling their femininity with recognition for their intellectual pursuits. In the case of experimental science, this will be illustrated in the next chapter with reference to Hertha Ayrton and her struggle to achieve parity in the laboratory.

[84] All quotes in this paragraph from LUSA, Young Papers, D140/37(misc. notes).

Chapter five

The laboratory: a suitable place for a woman?

Women, masculinity and laboratory culture

In his inaugural lecture in 1871, James Clerk Maxwell, recently appointed Professor to the soon to be opened Cavendish Laboratory at Cambridge University, stressed that his new facility's prime focus would be experimentation for illustration and for research. One of his first projects was to repeat the experiments of the 'great man' to whom the new laboratory was dedicated. In Henry Cavendish's day (d. 1810) there was, as yet, no instrumentation with which to measure an electric current, so Cavendish passed the current through his own body and estimated its magnitude by the intensity of the resulting shock. In keeping with the experimental bravery of his facility's namesake, Maxwell set up similar apparatus at the new Cavendish Laboratory

> ...and all visitors were required to submit themselves to the ordeal of impersonating a galvanometer. On one occasion a young American astronomer expressed his severe disappointment that after travelling to Cambridge on purpose to meet Maxwell and consult him on some astronomical topic he was almost compelled to take off his coat, plunge his hands into basins of water and submit himself to a series of electrical shocks![1]

Not surprisingly, given Maxwell's encouragement of a culture of physical courage and stoicism, women at Cambridge were not welcomed at the Cavendish Laboratory during his tenure. It was only in 1882, during the professorship of his successor, Lord Rayleigh, that women were admitted on the same terms as men.[2] An analysis of obituaries, memoirs and biographies of male scientists active in the decades surrounding 1900 presents a striking illustration of the way in which the laboratory was presented as a masculine space where heroic qualities

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[1] Alexander Wood, *The Cavendish Laboratory*, (Cambridge: Cambridge University Press, 1946), p. 4. One of Maxwell's projects was the publication of Henry Cavendish's electrical papers; connected to this, and also as a tribute to the generosity of the Cavendish family in endowing the laboratory, Maxwell deployed the resources of the Cavendish to repeat Cavendish's experiments and check his measures. To do so, Maxwell undertook investigations into the physiological effects of electric currents with himself as subject. Peter M. Harman, *The scientific letters and papers of James Clerk Maxwell*, 3 vols (Cambridge: Cambridge University Press, 1990-2003), vol. 3, pp. 11-13.

[2] Maxwell was not wholly antipathetic to women in science however; correspondence with his wife, Katherine Mary Clerk Maxwell, reveals communication about his work and other scientific issues. Ibid., vol. 2, p.122, p. 528, p. 623 and p 629; vol. 3, p. 873.

could be tested, developed and displayed. So a reminiscence of James Dewar, who experimented on the liquefaction of gases in the early 1900s, highlights the 'personal courage' and 'iron nerve' that his work required. When 'an alarming explosion rent the air of the laboratory' Dewar 'did not move a muscle, or even turn to look'. This memoir continues:

> Dewar never admitted that anything was dangerous. The most he would say was that it was a little tricky. Considering that Lennox and Heath, his two assistants, each lost an eye in the course of the work, this was certainly not an overstatement.[3]

Such daring in the laboratory and the forbearance of uncomfortable physical conditions are common in the recollections of men of science. Even if some of these memoirs are apocryphal, that the laboratory was represented as a site of manly display and the development of moral and physical courage, as well as of the production of knowledge, is significant when considering the experiences of women in science and the representation (or lack of it) of women in the laboratory.[4]

Aims

Until recently, women's absence from the laboratory has been explained largely by the growing institutionalisation of science at the end of the nineteenth century which acted as a barrier to women's participation. As the tradition of home laboratories gave way to new, specialised, experimental facilities, so women were marooned in the domestic sphere from which science had fled[5]. Recent scholarship has revealed a more complicated picture by uncovering previously 'invisible' women and following them into the laboratory[6]. Responding to this new visibility of women, this chapter suggests that the new professional scientist's need for moral and material status necessitated the representation of a heroic laboratory culture which was antithetical to femininity and, by necessity, ignored female experimenters. This discourse worked alongside the forces of professionalisation and institutionalisation - forces which require unpackaging to reveal the complex mechanisms of inclusion and

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[3] Lord Rayleigh, Robert John Strutt, 'Some reminiscences of scientific workers of the past generation, and their surroundings', *Proceedings of the Physical Society*, 48, (2) (1936), 216-246 (p. 230).
[4] More recently, 'manly' behaviour and a marginalization of women has been shown to be a dominating factor in mid-late twentieth century particle physics laboratories in the USA and Japan. See Traweek, chapter 3, 'Pilgrim's Progress: Male tales told during a life in physics', pp. 74-105.
[5] For example see Abir-am, pp. 3-4.
[6] For example, Gould, 'Women and the culture of university physics', and Richmond, 'A lab of one's own'.

exclusion. The term 'laboratory culture' is used here in a broad sense to encompass both the shared experiences of workers in the laboratory and the way in which these experiences were represented to a wider public. The primary focus will be on physical laboratories, as this was where Hertha sought to work and where the representation of a heroic, manly culture reached its highest potential. Biological, chemical and other specialist laboratories present with their own histories, culture and aesthetics which necessitate further, individual analysis.[7] Anecdotes of laboratory life developed into a mythology which was picked-up by journalism and fiction (which in turn reflected it back to the laboratory) and which was shared by both scientific and non-scientific audiences alike. To illustrate this, it is necessary to adopt an inclusive approach which goes beyond the testimony of scientists and scientific writing to include literary, fictional and photographic sources too. In this way, the processes that worked to affect the experiences, expectations and representations of Hertha and other woman active in experimental, laboratory-based science begin to be uncovered.

The growth and significance of laboratories

The closing decades of the nineteenth century have come to be described by historians of science as the years of the 'laboratory revolution'. Between 1880 and 1914 there was an enormous growth in institutional laboratories as the older 'devotee' tradition of research undertaken by gentlemen at home gave way to a new professionalism, and as the universities embraced the newer natural sciences that required experimental facilities. By end of century laboratories were used for teaching, research and commercial purposes, plus they could function as workshops and places of production as well as of discovery. Amid fears that Britain was trailing behind Germany in technical innovation, well-equipped laboratories and workshops became symbolic of national well-being and a key instrument in the race for international competitiveness. In the universities, possession of experimental facilities was becoming increasingly important and women's colleges were not left out of the expansion. At Cambridge, chemical laboratories were built at Newnham and Girton Colleges in 1879, and the Balfour Laboratory for Life

[7] For example, representations of biological laboratories are often informed by aesthetic considerations and refer back to different traditions. For H.G. Wells' Ann Veronica, the biological laboratory at the Central Imperial College, where she was studying comparative anatomy, 'had an atmosphere that was all its own ... (and) ... it made every other atmosphere she knew seem discursive and confused ... the room was more simply concentrated in aim than a church .... this long, quiet, methodological chamber shone like a star seen through clouds'. Wells, p. 115.

Sciences for Women at Cambridge was opened in 1884. At the end of the century Bedford College, London, possessed six new laboratories, erected at a cost of more than £6000, and Royal Holloway College, established in 1887, boasted well-equipped chemical and biological laboratories. The former prompted *Nature* to remark that it was 'surely a hopeful sign that a college for the education of women should now be regarded as incomplete unless it contains physical and chemical laboratories specially designed and fitted for the delivery of lectures and performance of experiments'.[8] However, that scientific women in universities were largely catered for with parallel facilities limited their impact on the culture that grew up around laboratory experimentation; this gender separation also suggests a disquiet about women sharing the laboratory space with men.

In the limited instances where laboratory facilities were shared, women were a small minority. Only a handful of women have been identified as 'researchers' at the Cavendish Laboratory in the nineteenth century[9] and, as discussed in chapter three, Hertha was one of only three women amongst 118 men when she embarked on an evening course in electrical and applied physics at Finsbury Technical College in 1884.[10] Even when the emphasis was on training science teachers rather than on technology and industry, women's participation was negligible. In 1896-7 seasonal courses offered by the Royal College of Science at South Kensington (the Central's partner institution) were attended by 300 men but only six women. The previous year's short summer courses, with an emphasis on practical laboratory work, had attracted 202 male and ten female students. The compiler of these figures, writing in 1897, placed the blame for this under-representation on women themselves for failing to take advantage of the academic opportunities placed within their reach.[11] This is a criticism not unfamiliar to modern ears and one which suggests a more subtle causation of women's absence. Historians of women and science have demonstrated the ways in which the growing institutionalisation of science worked to keep women out, however the cultural meaning of the laboratory and its effects on women have been largely overlooked. The laboratory's moral currency as a venue in which to develop and exhibit manly character, plus the increasing significance to national pride and virility of success in this experimental, knowledge-

[8] *Nature*, 61 (January 23, 1890), News, p. 279.
[9] Gould, 'Culture of university physics', pp. 132-137.
[10] LGU, 29,973.
[11] Bremner, p. 181.

and-technology producing space, were all elements which interacted to keep women to the periphery. Even the tradition of home-based laboratories, which did not disappear entirely but co-existed with institutional laboratories, did little to render women more visible in science, as Hertha's career illustrates.

The laboratory as a site of manly display

The tendency to represent the laboratory as a site of manly display, heroic endeavour and moral bravery, as illustrated above, created an inevitable ambivalence towards femininity. Writers of scientific memoirs used experimental work as a vehicle for constructing personas that recall the adventurer-heroes of Edwardian fiction such as Conrad's Marlow (*Heart of Darkness*) or H. Rider Haggard's Allan Quatermain (*King Solomon's Mines*).[12] Speaking of the Cavendish Laboratory, one researcher remembered being a near-victim to wires so arranged overhead that they threatened passers by with decapitation, and recalled battery cells containing nitric and sulphuric acids which 'what with the fumes which assailed one's throat and the acid which destroyed one's clothes' were 'a most disagreeable business'.[13] One British visitor to Edison's laboratory in the States likened the great man to Napoleon the First and affirmed that 'All one hears about his working three or four days and nights at a stretch is quite true: he has about 100 assistants, and manages, I hear, to keep them working all night too very often'.[14] It was 'family legend' in Hertha and William Ayrton's household that while running a teaching laboratory in Tokyo, Ayrton 'after two suicides and a murder ..... discouraged ritual sword-wielding by discharging a large revolver into the ceiling of his small laboratory'.[15] A photograph of Rayleigh's laboratory at the Royal Institution, where he performed work leading to the discovery of argon, has caught the culture of the physical laboratory by giving emphasis to a sign hanging from the ceiling that warns simply 'DANGER' (figure 5.1). In some accounts, the harsh

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[12] It is noticeable in these adventure novels that women tend to be absent or represented as unnatural beings. As Quatermain explains prior to narrating his story: 'There is Gagoola, if she was a woman and not a fiend. But she was a hundred at least, and therefore not marriageable, so I don't count her. At any rate, I can safely say that there is not a *petticoat* in the whole history'. H. Rider Haggard, *King Soloman's Mines*, (Hertfordshire: Wordsworth Editions, 1998), p. 10. (This novel was first published in 1886.)

[13] Rayleigh, *Life of J.J. Thomson*, p. 51 and p. 26.

[14] Ibid., p. 31.

[15] Graeme J.N. Gooday, 'Ayrton, William Edward (1847-1908)', Oxford Dictionary of National Biography (Oxford: Oxford University Press, 2004), <http://www.oxforddnb.com/view/article/30509> [accessed 29 January 2005].

physical environment of the laboratory is heightened by competitiveness, mainly for scarce equipment, redolent of the public school playing field. The 'danger' of Rayleigh's laboratory was augmented by its laboratory store being 'regarded as a plundering ground by the Scottish marauders from downstairs' (the chemists in the basement).[16] In the face of these trials and challenges, the scientist in his laboratory was objective and calm under pressure, doing his job just as professionally as the colonial administrator in similarly difficult and potentially dangerous places. In this way, the laboratory researcher's identity managed to combine the rationalism of scientific methodology with the heroic potential of experimental work.

Unease with how a female scientific experimenter should be presented is reflected in the nature and scarcity of fictional and journalistic representations of the day. It is rare to find a woman pictured as an active researcher and experimenter (as opposed to a student) in the laboratory. Science and scientists were a favourite subject for the rapidly expanding Edwardian periodical and magazine press yet a study of media science before 1914 mentions no women scientists as subjects of reports (although there were a significant number of women science writers: women were accepted as popularisers of science for an amateur or child audience and could call on a tradition of such female authors to justify their work).[17] Ideas concerning the biological and emotional unsuitability of women for dispassionate intellectual labour and the dangers to health and fertility that might accompany attempts at such manly pursuits (loss of beauty, fertility and womanhood) were a theme that added to a nervousness of representing women as scientists or experimenters within the same frames of reference as were applied to men.[18] The valorisation of scientific heroes in the periodical press was contrasted by a common fictional portrayal of scientists as male, unemotional, detached 'and, at worse, inhuman and insane'.[19] This was the ideal of the 'objective' scientist pushed to extremes, an example of masculinity in direct opposition to passionate, empathetic femininity. The decades of the laboratory revolution were also when the new genre of 'scientific romances' (H.G. Wells, Jules Verne, Robert Louis Stevenson) became

[16] Rayleigh, 'Reminiscences', p.226.
[17] Peter Broks, *Media science before the Great War* (Basingstoke: Macmillan, 1996), pp. 30-31.
[18] For a discussion of scientific theories supporting female intellectual inequality see Fiona Erskine, 'The *Origin of Species* and the science of female inferiority', in *Darwin's 'The Origin of Species': New interdisciplinary essays*, ed. by David Amigoni and Jeff Wallace, (Manchester: Manchester University Press, 1995), pp. 95-121.
[19] Broks, p.43.

popular. Much of the fast-growing output of magazine fiction also used science or scientific ideas as a favourite theme with stories written following the tradition of Faust, Frankenstein and the gothic novel. Here we can see laboratory culture and popular culture spilling over and informing each other. It has been noted that in these texts it is often the laboratory which has 'diabolical connotations' and is the site of danger and evil.[20] It is possible that these representations had associations with the growth of a descriptive language which emphasised courage and manliness in the experimental space. The laboratory signified a place of unease in some parts of popular literary culture and, as these stories often stood alongside 'factual' accounts of science and scientists, it can be assumed that science and science fiction had a reciprocal effect upon each other.

The stereotype of the laboratory as a dangerous place calling for physical and psychological bravery and endurance by necessity omits any feminisation or representation of women. It is difficult to find evidence of the experiences of women who worked in this environment; no wonder there is little scholarship in this area. Marsha Richmond has written on the history of the Balfour Biological Laboratory for Women at Cambridge University and notes an undercurrent of prejudice against the few female research workers (as opposed to undergraduate students from Newnham and Girton who attended lectures and demonstrations there) which 'could sometimes turn into hostility and make working there problematic'. She quotes a male researcher talking about Cambridge in the 1890s:

> At that time women were rare in scientific laboratories and their presence was by no means generally acceptable - indeed that is too mild a phrase. Those whose memories go back so far will recollect how unacceptability not infrequently flamed into hostility.[21]

Although laboratories were built at some women's colleges in the first decade of the twentieth century, as previously outlined, these were mostly teaching, not research, institutions. At Cambridge, their function was to offer routine instruction to female undergraduates who were segregated in their own facilities and did not (as a rule) have opportunity to undertake novel experimental work. As a result, these scientific women did not pose a threat to the reproduction of manly values within University-wide facilities which owed their reputation to research. As late as 1911, William Ramsay at University College London was

[20] Ibid., pp. 41-51.
[21] Richmond, 'A Lab of one's own', p. 256.

reported to 'rather discourage women in his laboratory for research purposes'[22] and the environment at the Cavendish Laboratory could be similarly antagonistic to female researchers, exacerbated by overcrowding. J.J. Thomson, an assistant and then Professor of Experimental Physics there, recalled an episode in the 1890s that 'appealed to his sense of humour'. A 'lady student' from Newnham or Girton had fainted and a laboratory boy, 'anxious to rise to the occasion, thought it right to turn the fire hose on her!'[23] Women were in a precarious position whether they sought admission to research or teaching facilities, their admission was not by right and, often tolerated rather than welcomed, they were subject to the whim of male dons. For example, in 1887 Adam Sedgwick threatened to turn women out of his Cambridge morphology laboratory if they did not stop agitating for degrees.

Femininity in the laboratory: An uneasy combination

If laboratories held significance for masculinity, women's presence could be transgressive; in contemporary accounts this unease leads to a denial of women in the laboratory or their portrayal as objects of amusement. At Cambridge, women were not admitted until comparatively late to the University Chemistry Laboratory (1909) and were barred from physiology practicals until 1914. Richmond notes how women were excluded from the Cambridge Natural Sciences Club and from informal departmental and formal college tutorial systems and prizes. Ever enterprising, the women of the Balfour set up their own intellectual and social networks. This creation of parallel facilities, echoing and hand-in-hand with the provision of women's colleges, was one way that women sought to create a more feminised scientific environment. Paula Gould has managed to follow a handful of women who worked as researchers around 1900 through the doors of the Cavendish Laboratory. Despite characterising the laboratory as 'a community built upon masculine ritual and tradition' Gould emphasises integration rather than confrontation and argues that women became 'part of a team and not interlopers'.[24] Certainly the regime was more woman-friendly during the professorship of J.J. Thomson's successor, Lord Rayleigh. However, it is hard to reconcile recollections that position women as figures of fun or

[22] Carol Dyhouse, *No Distinction of sex? Women in British Universities, 1870-1939* (London: UCL Press, 1995), p. 144. William Ramsay was Professor of Chemistry at University College London from 1887-1913; he received a Nobel prize in conjunction with Lord Rayleigh in 1904.
[23] Rayleigh, *Life of J.J. Thomson*, p. 46.
[24] Gould, 'Culture of Physics', p.129.

irrelevancy as recalling a situation of comfortable integration. Certainly, some of the researchers, notably Eleanor Sidgwick (one of the Balfour family, wife of Professor Henry Sidgwick) and Rose Paget (daughter of Sir George Paget, Professor of Physics) were part of the social network at Cambridge and their cordial family relations with Thomson or Rayleigh may have extended into the laboratory.[25] Neither of these women had been students at Newnham or Girton. Rayleigh's account of Paget's and Thomson's courtship shows how inconsequential the work of women was represented:

> In 1889 Miss Paget did some research work at the Cavendish Laboratory on soap films thrown into stationary vibration by sound, after the fashion of Sedley Taylor's phoneidoscope. J.J. found that she needed some help in these experiments....... J.J. would come in, and say 'I must go upstairs for a few minutes', which very easily expanded themselves, by 'Relativity' perhaps, into an hour. One day he came down looking highly delighted, and Miss Paget went out with a flush on her cheek, and did not continue any more experiments.... After six weeks' engagement they were married.....'[26]

A few years later, Mrs J.J. Thomson's role in the laboratory was typified during the opening of new laboratory buildings by the task of receiving the guests while holding a bouquet of flowers, the gift of the research students. It is likely that relations between the sexes in the laboratory were, for the most part, polite and cordial, but women were absent from the masculine image that the Cavendish and other research facilities wished to present to the public.

The above accounts of late nineteenth and early twentieth century laboratory life use models of moral courage and perseverance to construct a model of scientific manhood. It is difficult to position women within these narratives except as figures of amusement, oddity or romantic interest; it is easier to omit them all together. This is one reason why it is so difficult to get a clear picture of women's everyday experiences in the laboratory. Appreciations of Hertha differ from those of her male contemporaries by a lack of emphasis on her experimental work, despite her exhausting and sometimes dangerous research on

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[25] Gould divides the female researchers at the Cavendish into two groups, those who were from a 'free-thinking' or foreign background and others whose presence at the Cavendish was part of a pattern of intellectual life common to Victorian gentlewomen and Cambridge families. Gould, 'Culture of Physics, pp. 134-137.

[26] Rayleigh, *Life of J.J. Thomson*, p. 34.

large-flame electric arcs.[27] Even the announcement of the award of the Royal Society's Hughes Medal for original discovery in the physical sciences to Hertha in 1906 is notable for its brevity, the concentration on results rather than on any arduous process to attain them, and a lack of celebration – or even evaluation - of her work:

> Mrs Ayrton's investigations cover a wide area. She discovered the laws connecting the potential difference between the carbons of an arc with the current and with the distance between them, and proved these to apply not only to her own experimental results but to all the published results of previous observers. Dealing with the modifications introduced into the arc by the use of cores in the carbons, she found the causes of these modifications. The peculiar distribution of potential through the arc was traced, and its laws were discovered by her.
>
> Having found the conditions necessary for maintaining a steady arc, and for using the power supplied to it most efficiently, she was able to explain the cause of 'hissing', and the causes of certain anomalies in the lighting power of the arc.
>
> For the past four years Mrs Ayrton has been engaged in investigating the causes of the formation of sand ripples on the seashore.'[28]

Other individuals awarded medals at the same time as Hertha received praise for the value of their work and the method by which it was achieved. The recipient of the Copley Medal had provided 'distinguished services', 'brilliant memoirs' and was in the 'first rank of investigators'; the Royal Medal was awarded to Alfred Greenhill for his 'remarkable' work 'characterised by much originality, and by a rare power and skill' and to Dukinfield Henry Scott for his work which was of 'first-rate importance'. The recipient of the Darwin Medal was noted for 'extensive experiments that have been carried on for many years' with results 'of great importance' and 'considerable influence'.[29]

Hertha's prize-winning work on the electric arc had been carried out at the Central Institute from 1893 to around 1904. It is difficult to follow her into the laboratory as her presence, arranged informally by her

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[27] For example, Armstrong's obituary in *Nature* is dismissive of Hertha's scientific abilities as 'overpainted' and focuses more on personal details: Armstrong, 'Mrs Hertha Ayrton', pp. 800- 801 (p. 801).

[28] 'Anniversary Address', *Proceedings of the Royal Society of London*, Section A, 79 (1906), 1-12 (p. 12). The terseness of this announcement may reflect the discord within the Royal Society as a whole, and within the council, over the award of a medal to a woman.

[29] Ibid.

husband, is rarely noted in any existing archive of the institution. This relative 'invisibility' in college history is significant when it is remembered that Hertha's work here was aided by Central staff and students and led to the award of a prestigious Royal Society Medal – surely an important event for a college striving to win credibility as a professional institution on a par with the universities. Yet, most important for the Central, was to prove itself capable of producing 'trained men' and 'professional engineers' who were able to maintain 'the whole status of the profession'[30]. This required promoting an image of itself as producing graduates with the robust (masculine) practical and leadership skills to build dams, construct electric light schemes or create new locomotive systems throughout the world. As discussed in chapter three, this ideal of manly scientific citizenship was essential to the Central's efforts to establish itself as a provider of education that was equal (albeit different) to that provided by the long-established universities. A woman in the laboratory, no matter how successful her work, would not aid the promotion of this image. A nervousness of showing women in the laboratory was not confined to the Central Institute. For example, an article on Girton College in a contemporary periodical was not atypical in showing well-equipped, tidy but empty laboratories.[31] The new women's colleges were wary of provoking criticism from opponents who argued that women jeopardised their well being by following a programme of education similar to men's. Darwinian fears that exposing women to hard intellectual work could lead to a loss of health, fertility and beauty, were exacerbated by imagery that presented the laboratory as a harsh and competitive environment that threatened accepted norms of femininity. At University College London in the late 1880s, one female student was discouraged from seeking admission to chemistry classes as it was believed that women would be 'scarred for life and have their clothes burnt off them as the men threw chemicals around'.[32] The dangers inherent in the laboratory meant that it was an inappropriate place for a woman.

Hertha in the laboratory

Yet a glimpse of Hertha's experiences in the laboratory can be gleaned from the 1903 book which resulted from her researches.[33] Far from being

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[30] LGL, 29,956 (*Central Gazette*, 1 (1) (1899), 75).
[31] Garriock, p. 109.
[32] Dyhouse, *No distinction of sex*?, p. 33.
[33] Hertha Ayrton, *The Electric Arc*, p vi.

a figure of amusement, it is clear that she established warm relationships with the staff and students who assisted her in experimental trials of carbons while following their diploma course. C.E. Greenfield, a student at the Central 1899-1903, later worked with Hertha in her home laboratory after her husband's death. Another co-worker at the Central, her husband's Chief Assistant Thomas Mather (who had worked with Ayrton on arc lights) rushed to Hertha's defence in a letter to *Nature* in response to an unsympathetic obituary which had accused her of a lack of originality.[34] In the preface to *The Electric Arc* Hertha thanks Mr. Mather for his valuable advice and assistance with experiments. Mather had superintended the first set of experiments and made suggestions which simplified their execution. In order to adequately monitor the carbons, a mirror was now used to reflect the phenomenon onto a large screen of white cartridge paper. This improved visibility was vital to Hertha's research which depended on observing the carbon and spotting minute changes over long periods of time. It was painstaking work which required keeping an arc under a steady current controlled by hand for periods of an hour or more while monitoring the results. (Hertha likened this process to the driving of an obstinate animal after learning its caprices.) Another of Ayrton's assistants at the Central, Mr Phillips, made a similarly important contribution to the design of Hertha's experiments, introducing the use of a tubular carbon to ensure that the arc did not extinguish when air was blown on to it.[35] Effective teamwork and experimental facilities able to host lengthy, controlled experiments were indispensable. The relationships that Hertha achieved with co-workers at the Central were therefore vital to her work.

Challenging the pure and practical hierarchy

Given recent research revealing women in the laboratory, it is important to ask why their presence has for so long been obscured, not least by 'manly' representations of laboratory life of the kind described above. Despite the growth in number and prestige of laboratories (and the increasing recognition of their key role in achieving trade dominance) any hint of commercialism could still taint a researcher's work, as outlined in chapter three. In 1903 astronomer William Huggins, in his presidential address to the Royal Society, made implicit criticism (possibly aimed at Ayrton, his colleague Perry and their fellow

[34] Mather, 'Mrs Hertha Ayrton'.
[35] Hertha Ayrton, 'The reason for the hissing of the electric arc', *Nature*, 60 (July 27, 1899), 302-305 (p. 304).

modernisers) of fellows who worked not out of ideals of service but for profit, when he stated that the Society had achieved its unique position '.... by its unwearied pursuit of truth for truth's sake without fee or reward'[36]. Men receiving money as a result of their scientific researches could jeopardise their credibility; for women to do so would be to transgress middle-class conventions of femininity and jeopardise social standing too. Emphasising the heroic qualities involved in research (perseverance, bravery, 'iron nerve') helped win prestige and moral currency at a time when science as a profession was still in the process of negotiating an identity and a space. For similar reasons, practical scientists and engineers constructed arguments for their own integrity based on their profession as providing 'good' to society. Modern engineers presented themselves as the bringers of progress, taming and domesticating physical forces and presenting them as a service to man (and woman) kind. Such discourse tended to imbue laboratory methodology - observation, experimentation, reason - with moral value, a view neatly presented in a Royal Society obituary which remarked that 'Scientific investigation is eminently truthful. The investigator may be wrong, but it does not follow (that) he is other than truth-loving'.[37] Here it is the method of science that bestows moral righteousness, not the correctness of any results that the experimenter may produce.

The merit of experimental work was also promoted for the valuable moral training it conferred. At Oxbridge and public schools, success in the laboratory or site of scientific experimentation was becoming as important as the playing field for the development of moral character;[38] and the adoption of an active, scientific methodology began to be presented as a paradigm of how the modern citizen should manage life. Everyday problems were to be approached with objectivity and clarity of thought - just as researchers in the laboratory approached their experimental tasks. If the laboratory was a space where manliness was developed and displayed, women's presence was problematic. For Conan Doyle's Sherlock Holmes (who was the epitome of precise scientific rationality) women were 'never to be trusted - not the best of

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[36] Sir William Huggins, *The Royal Society, or, Science in the State and in the Schools* (London: Methuen, 1906), p. 40.

[37] Royal Society of London, 'Sir George Gabriel Stokes', in *Proceedings of the Royal Society of London: Containing obituaries of deceased fellows, chiefly for the period 1898-1904*, 75 (1905), 210-216 (p.215).

[38] Larry Owens, 'Pure and sound government: Laboratories, playing fields and gymnasia in the nineteenth-century search for order', *ISIS* 76 (1985), 182-194 (p. 193). (Owen's focus is on the USA.)

them'.[39] This remark reflected views still articulated by some (but by no means all) followers of the new evolutionary approaches to science. Experimental research required the objective production and presentation of data, the capacity to abstract from the particular to the general, the intelligence to design, interpret and replicate experiments, plus the ability to focus without distraction. Darwinists such as Armstrong and Galton doubted whether women, who were designed by evolution to be emotional and partial, with a tendency to shift attention and achieve only surface understandings, could be trusted to do science. Women were competent in their 'natural' role as wives and mothers, but they were intellectually and temperamentally unsuited to scientific work: women's procedures and results simply could not be relied upon without question.

A connecting factor which helped to keep women at the periphery of laboratories was the practical sciences' competition with mathematics for status, a rivalry which will be discussed in more detail in chapter six. The natural sciences tripos at Cambridge had been established in 1851 and, until the mid 1870s, it had been viewed largely as the poor relation to mathematics. In his memoir of J.J.Thomson, Lord Rayleigh (son of the Nobel prize-winning physicist of the same name) remarks in connection with the Cavendish Laboratory that prior to around 1865 the tradition of physical science at Cambridge had been somewhat antagonistic to experimental research. Since the 1870s however, all that had changed.[40] This process had continued and, by the mid 1890s, mathematics (which had long been a signifier of manliness) had become unfashionable amongst a majority of male students at Cambridge who, in preference, sat the natural sciences tripos. Furthermore, as the new women's colleges retained their preference for mathematics, with increasing numbers of students from Girton and Newnham taking honours in the mathematics tripos, the discipline became less antagonistic to contemporary notions of femininity. (This process will be explored in the following chapter.) By the late nineteenth century, studying mathematics alone did not provide the endorsement of masculinity that it had earlier offered; nor did it promote the active masculinity now exhibited by the practical mathematicians, experimentalists and engineers in the vanguard of so much technical progress. Although the Cambridge mathematics tripos was still an important route of entry into experimental science until the late 1880s, the ending of the tradition of 'mixed maths', the infiltration of analysis,

[39] Kesiner, p.2 .
[40] Rayleigh, *Life of J.J. Thomson*, p. 15.

and the addition of higher mathematics to the natural sciences tripos, had all reinforced the perception of mathematics as less relevant to the physical world. This attitude is reflected in Lord Rayleigh's remark in a Royal Society Presidential Address that in some branches of Pure Mathematics it is said that readers are scarcer than writers.[41] Rayleigh's comment also conveys some of the unease and suspicion that can sometimes be engendered by a minority group engaged in producing inaccessible - even 'cabbalistic' - learning.[42] Engineers and experimentalists constructed an active, virile identity in the laboratory in part to highlight their difference from the pure mathematicians and so enhance their status relationship.

Home laboratories and the gendering of space

Whatever the cordial relationships that individual women may have established with co-workers in the laboratory, their presence did not rest easily within the culture and image that male workers liked to present. Hertha undertook research at the Central laboratory only while her husband was professor there (her work a continuation of his experiments on the electric arc). After Ayrton's death in 1908, and the subsequent loss of his patronage and support, Hertha's tenuous and informal connection with the College was severed. As a woman, it would have been difficult for her to step into her husband's shoes or assume another teaching or research role at the College; when Pierre Curie died in 1906, even Marie Curie (who in 1903 was joint recipient of a Nobel prize with her husband and Henri Becquerel)[43] found it difficult to fulfil her hopes of continuing her work by taking over his professorship at the Sorbonne. Marie only succeeded in securing the appointment after special intervention by friends and supporters.[44] After Ayrton's death, Hertha transferred her attic laboratory into the drawing room of her London home and it was

[41] Lord Rayleigh, 'Address of the president, Lord Rayleigh, O.M., D.C.L., at the anniversary meeting on November 30th, 1907', *Proceedings of the Royal Societ y of London, Series A*, 80 (1907-8), 231-251 (p.243).

[42] Felix Klein and the Göttingen School of Mathematics attracted similar suspicions in the era before WW2, articulated by way of a supposed conspiracy of Jewish mathematicians: 'Jews were innately inclined toward algorithmic, analytic, or abstract thinking, whereas Germans tended to think intuitively and synthetically, often drawing their inspiration from natural phenomena.' David E. Rowe, ' "Jewish Mathematics" at Göttingen in the era of Felix Klein', *ISIS*, 77 (3) (1986), 422-449 (p. 424).

[43] There was contention surrounding Marie's nomination: she was deliberately excluded from the first nomination, her name only included after pressure from an influential member of the Swedish Academy of Sciences, mathematician Gustav Mittag-Leffler. See Susan Quinn, *Marie Curie: A Life* (Cambridge MA: Da Capo Press, 1995), pp. 187-190.

[44] Helena M. Pycior, 'Pierre Curie and "His eminent collaborator Mme Curie": Complementary partners', in Pycior, pp. 39-56 (p.56).

here that all her experimental work was undertaken until her death in 1923, fifteen years later.

Historians have written extensively about a late nineteenth century ideology that divided space according to gender and function. Separate spheres placed the (middle class) woman in the home and men in the great world beyond; scholars of space have emphasised how women, as signifiers of moral virtue and social status, could not cross social and physical boundaries as men were able to do.[45] One of the strategies of the suffrage movement was to challenge this gendered occupation of space as women marched through the streets and took to public platforms to argue their case. As a member of the militant Women's Social and Political Union (WSPU), Hertha was closely involved with 'the Cause'; her campaign to be an equal member of the scientific community alongside her male peers ran parallel to her fight for the vote. Indeed, she saw both issues as separate facets of the same problem: the need for equality between the sexes. The controversial campaign of the WSPU, and the highly-public role assigned to Hertha within it, may well have added to the difficulties that she faced in gaining access to scientific institutions. It also added to reservations about the presence of women in the laboratory and made the issue even more contentious. As will be discussed in chapter seven, the actions of the WSPU were regarded by many (even within the wider suffrage movement) as illogical, if not 'hysterical' - attributes which were coded feminine and seen as the direct opposite of the empirical, objective and unemotional methodology of experimental science.

Although the explanatory power of separate spheres has been increasingly challenged as providing too rigid a division, especially when applied to turn of century, it is clear that men and women shared few spaces on equal terms; women were defined by the home in a way that men were not. Although many male scientists had home laboratories, after the 'aristocratic house' tradition, by the late nineteenth century rarely were they the only venue for experimental work that these men had access to. That gentlemen's 'country house' laboratories continued at turn of century has been interpreted as a means to reconcile the idealism and spiritual value represented by the older scientific 'devotee' tradition with modern laboratories producing commercial

[45] Shirley Ardener, 'Introduction', in *Women and Space: Ground rules and social maps*, 2nd edn, ed. by Shirley Ardener (Oxford: Berg, 1993), pp. 1-15 (p.5).

applications alongside new knowledge.[46] This strategy, alongside that of representing the laboratory as a place of manliness and heroism, worked to assuage the new professional scientist's need to convey integrity and moral worth. Lord Rayleigh had developed large laboratories at Terling and a smaller one at his previous home in Cambridge, yet he also researched and held professorships at the Cavendish Laboratory and the Royal Institution, and was later associated with the new National Physical Laboratory. William Crookes experimented at home as well as undertaking joint work at the Royal Institution. George Gabriel Stokes carried out most of his research at a modest home laboratory but simultaneously held a Cambridge Professorship. It was the connection of these laboratories to a wider institutional and scientific network that helped preserve their credibility and integrity as viable places of experiment.

But these home laboratories were not all modest. Upon inheriting Terling Place in 1873, Lord Rayleigh installed a private gas works to feed bunsen burners and blowtorches, and developed the existing laboratory into a complex of experimental facilities. These consisted of a 'book-room', a workshop, a chemical room and a photographic darkroom. Above these on the main floor was the main laboratory, partitioned into a number of areas, including the 'black room' which was equipped with a helioscope and a spectroscope and used for optical experiments.[47] Crookes' private laboratories consisted of a suite of rooms including a physical laboratory, chemical laboratory, workshop and library.[48] Experimental activities at these home laboratories were endorsed by the Royal Society of London of which all these men were fellows (and presidents in the case of Rayleigh and Crookes), a validation and honour denied to women. Working only from home, without position, implied amateur status by the closing years of the nineteenth century. After all, anybody could perform simple experiments in their home, as was encouraged by a series of articles entitled 'Science for the Unscientific' appearing in a popular periodical from 1894. Through experiments to be executed at home the series explored subjects such as electricity, air

[46] Simon Schaffer, 'Physics laboratories and the Victorian country house', in *Making space for science: Territorial themes in the shaping of knowledge*, ed. by Crosbie Smith and John Agar (Basingstoke: Macmillan, 1998), 149-180 (p 177).
[47] A.T. Humphrey, 'Lord Rayleigh: the last of the great Victorian polymaths', *GEC Review*, 7 (3) (1992), 167-180. Available online: <http://www.marconi.com/Home/about_us/Our%20History/Publications%20Archive> [accessed February 13 2005]
[48] Rayleigh, 'Reminiscences', p. 238-240.

pressure and optical illusions.[49] Hertha's home laboratory contributed to her remoteness from the networks and standards of the scientific community and had similar effects to her exclusion from the Royal Society.

It seems likely that Hertha's laboratory lacked credibility as a viable experimental site at a time when increasing emphasis was being placed on precise measurement and the use of manufactured instrumentation.[50] The standardisation of values in areas such as electromagnetism and electrical resistance were of immense importance to securing the integrity of the international cable system and, as a result, extra demands were placed on the experimental space. In order to achieve exact results, laboratories were deemed to require specially-designed buildings and equipment which would aid replication of experiments and prevent any disturbance or contamination by the outside world which could distort findings. Arguments about the status of experimental findings could hinge on securing agreement on the acceptability of particular instrumentation, or on the viability of specific research technologies.[51] Whether experimental results were to be admitted as knowledge was now dependent on the credibility of their site of production, as well as on the trustworthiness of the 'men' of science who had produced them. By attempting to create a 'value-free' experimental space and quantifying and measuring their research findings, researchers attempted to give material expression to the 'objectivity' which was the lodestar of their experimental science. Just as these engineers, practical scientists and physical researchers were trying to dispense with the individual and present their conclusions as the 'view from nowhere,'[52] their counterparts in pure mathematics, that most deductive of disciplines, were foregrounding the individual intellect and doing precisely the opposite. By promoting 'objectivity' in this way laboratories were striving for status as privileged epistemological spaces and replacing older venues of scientific enquiry such as the museum, fieldwork or the personal study.[53] When Karl Pearson took over Francis Galton's Eugenics Record Office at University College London in 1906, one of his first acts was to rename

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[49] Broks, p. 37.

[50] For discussion of the expansion in scale, cost and time of experiments from this period see Nicholas Jardine, *The Scenes of Inquiry: On the reality of questions in the sciences* (Oxford: Clarendon Press, 1991), pp. 94-120.

[51] See Graeme J.N. Gooday, *The Morals of Measurement: Accuracy, irony, and trust in late Victorian electrical practice* (Cambridge: Cambridge University Press, 2004), pp. 23-39

[52] Schaffer, pp. 151-152.

[53] Gooday, 'Premisses of Premises', pp. 219-222.

it 'The Galton Eugenics Laboratory', although much of its work centred on statistical computation, measurement and the compilation of tables for family pedigrees and actuarial death rates.[54] New institutional laboratories vied with each other for prestige based on their laboratory equipment. The Cavendish Laboratory had a 'magnetic room' for experiments in which there would be no magnetic disturbances from iron fittings or pipes. A 100-ton testing machine was pride of place at the new National Physical Laboratory, while the Central College's new electrical laboratories boasted a 5kw Ferranti transformer and a travelling overhead crane to assist in experimentation.

A woman's laboratory: tensions and questions

It is significant that the quality and efficacy of Hertha's experimental apparatus was the focus of doubt and concern for the Royal Society on several occasions, leading to the rejection of a paper on sand ripples.[55] One referee questioned her research methods and characterised them as 'crude'[56]. In one of her papers on the subject, Hertha describes her methods. Initial experiments were executed with vessels of various shapes and sizes from a 'soap dish' to a 'pie dish', moving up the scale to a 'tank' forty four inches in length. Rollers or cushions were put under these vessels to enable smooth rocking (by hand or small electric motor) which caused the water oscillations. In this way she examined varying ripple formations and, by adding finely powdered aluminium to the oscillating water, made visible the characteristics of water vortices.[57] Hertha's experiments demonstrated that ripple marks were not formed by friction (as put forward by Professor George Darwin at Cambridge University) but were due to the processes of varying water pressure. According to Tattersall and McMurran, in the 1940s independent experiments with ripple tanks by Bagnold and Scott confirmed Hertha's conclusions, yet neither mentioned her pioneering results.[58] If Royal Society referees questioned her techniques, even sympathetic

[54] For a detailed description of the work of Pearson's eugenics laboratory, see M. Eileen Magnello, 'The non-correlation of biometrics and eugenics: Rival forms of laboratory work in Karl Pearson's career at University College London, Part 1', *History of Science*, 37 (1) (1999), 79-106 and 'Part 2', *History of Science*, 37 (2) (1999), 123-150, especially Part 2, pp. 126-136.

[55] Concern was raised that the pressure indicators attached to the tanks of water that she had used could have leaked and distorted the readings. Hertha redesigned the apparatus and her paper was finally accepted.

[56] Royal Society of London, Library, Archives and Manuscripts (RSL), Referee Report 143/1904 (The author was John Joly, Professor of Geology and Mineralogy at the University of Dublin).

[57] Hertha Ayrton, 'The Origin and Growth of Ripple Mark', *Proceedings of the Royal Society of London*, 84 (1910), 285-310.

[58] Tattersall and McMurran, p. 103.

contemporaries expressed mild scepticism and wrote of how hard it was to appreciate her ideas due to the 'toy-like models' used in her laboratory.[59] Another memoir describes Hertha's use of 'a morsel of feather on a single thread of silk, anchored to a hat-pin' with which to test the speed that coal gas is driven through tubes.[60] Yet, there is a gender difference here. Male scientists were applauded for their achievements gained with primitive apparatus, especially when these heightened the danger to the experimenter. Gabriel Stokes was celebrated for experimental work 'executed with the most modest appliances' and Rayleigh's Terling laboratory was famously said by Kelvin to be 'held together with sealing wax and string'.[61] John Aitken, working at his home laboratory in Falkirk, was praised for 'researches devised and constructed in his own hand'; his work tables were 'laden with glass-work, blow-pipes and many odds and ends of apparatus in the course of construction' yet, far from employing 'crude' methods, he possessed 'a real intuition for the devising of illustrative experiments. His one aim was to get at the truth'.[62] Such characterisation referred back to the romance of the earliest experimenters, such as those who founded the Royal Society in the 1640s, and linked the contemporary 'great men' of science with their forefathers. The tendency to highlight these older, more 'hands-on' experimental techniques may also have been a way for modern experimenters to assert their heroic credentials in the face of the increasing role of instrumentation which functioned as a barrier, and an intermediary, between 'men' and their science.[63]

Despite attempts to depersonalise and objectify the experimental space, trust was intimately connected with the researcher whose space it was - and that researcher's body was gendered. Gender has been notable by its absence from the recent debate on 'trust' in the history of science (an omission also discussed in chapter seven) but it is clear that women, mostly excluded from institutional and personal networks, and facing a Darwinian question mark over their intellectual capacity for science, did not easily acquire the credentials for 'trustworthiness'. Shapin and Schaffer, in the context of the seventeenth century, have argued that the

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[59] IEE, Trotter Memoirs, p. 587.

[60] Sharp, *Hertha Ayrton*, p. 282.

[61] Royal Society, 'Sir George Gabriel Stokes', p. 211; Humphrey, 'Lord Rayleigh', p. 8.

[62] Cargill G. Knott, ed., *Collected scientific papers of John Aitken: Edited for the Royal Society of Edinburgh, with an introductory memoir by Cargill G. Knott* (Cambridge: Cambridge University Press, 1923), pp. vii - xii. Aitken (1839-1919) researched air formations and other atmospheric phenomena.

[63] Thanks to the graduate seminar in history and philosophy of science, University of Leeds 2003, for this insight.

process by which a piece of work becomes accepted as knowledge rests on relations and conventions of trust between disinterested (and like) gentleman scientists.[64] Another view interprets the increasing importance of objective and transparent science, based on measurement and precise mathematics, as a way to replace any reliance on the skill, good intentions and veracity of the practitioner.[65] On both counts Hertha was on the losing side. Her laboratory did not have the credibility of a modern, 'value-free' experimental space; her sex made it difficult to forge working relations with male peers as she was barred from institutions such as the Royal Society which were vital for networking and reputation-building. Both of these difficulties informed each other, escalating the scepticism that Hertha faced as a female scientist and influencing the kind of investigations that she could perform.

Hertha was limited in the type of work that she could undertake in her laboratory which was simply not equipped to perform, say, electrical experiments requiring precise measurement. She found it increasingly difficult to persuade contemporaries to visit her home to witness her experiments and this was especially acute during the first months of the First World War when Hertha struggled to have any official interest taken in her anti-gas fan. One commentator, a President of the Institution of Electrical Engineers, refers with ambivalence to Hertha's laboratory as a 'laboratory-drawing room'.[66] A photograph of 'Hertha Ayrton in her laboratory' which, although undated, probably originates from 1906, the year that she received a Royal Society Medal, endorses this perception (figure 5.2). Hertha is positioned in front of a bookcase, a potted plant and vase are above each shoulder and paintings hang on the wall above her head. She stands in front of a table upon which is a barely visible glass tank. The edge of another glass tank can just be seen, resting on top of a table covered in a velvet cloth. Hertha herself is dressed as to receive visitors, wearing jewellery, avoiding our eyes by gazing out towards the right of the photograph. The apparent domesticity of her experimental apparatus means that there is no signifier of Hertha's profession in the portrait. The effect is ambiguous: is this a scientist in the laboratory? Or a hostess/woman in her drawing room? The tidy, domestic values so connected with notions of femininity can also be read from this image. Compare this to the messy, busy, active photographs of

[64] Shapin and Schaffer, especially chapter 4: 'The trouble with experiment': Hobbes versus Boyle', pp. 110-154.
[65] Porter, especially chapter 9: 'Is science made by communities?', pp. 217-225.
[66] Trotter, *Memoirs*, p. 587.

her contemporaries' laboratories (figures 5.1 and 5.3) and the visual subtext revealed by Hertha's portrait is that a woman's space is the home, not the laboratory.

When Hertha Ayrton's achievements were reported in the press, the emphasis was on her femininity as a source of wonder and amusement. For example, *The Times*, reporting on the award of the Hughes Medal to Mrs Ayrton, noted that her experimental methods were to be appreciated 'with interest and entertainment'.[67] In her biography of her friend, Evelyn Sharp cannot resist using Hertha's experimental enthusiasms as a means to introduce levity into her account. On the occasion of a dance at Hertha's home, hosted by her stepdaughter for her friends, Sharp writes that the

> guests were suddenly amazed to see an abstracted lady in an overall emerge from the laboratory at the top of the house (where she was using a good deal of current at the moment) and, muttering to herself, 'The main fuse will go!' proceed to switch off the electric lights without apparently noticing the presence of the revellers.[68]

Even a sympathetic novel, written by Edith Ayrton Zangwill and inspired by the life of her stepmother, uses the spectacle of a woman in the laboratory as a curiosity with which to generate humour:

> From the room within came a curious fizzling sound and a faint but still more curious odour. Some demented domestic appeared to be frying a late and unsavoury lunch in her bedroom. No servant would have condescended to a shapeless, blue-cotton overall and, still less, to hideous, dark goggles, made disfiguring by side-flaps ... all was dominated for the moment by a hissing jet of flame that darted out between the small, dark objects held in metal clamps which stood on a table in front of the girl ...[69]

The ambivalence of a woman in the laboratory is a theme of the novel, represented by the heroine's mother who names her daughter's laboratory the 'infernal regions' of the house and feels uncomfortable visiting there. The heroine's suitor also finds accompanying Ursula/Hertha into the laboratory personally uneasy. He remarks that he prefers to meet her in the park because she is 'less scientific, more

[67] Royal Holloway, University of London, Archive and Records, Bedford College Magazine, AS200/3/61 ('Mrs Ayrton and the Hughes Medal', *Bedford College Magazine*, 61 (December 1906), 13-14 (p. 14)).
[68] Sharp, *Hertha Ayrton*, p. 156. Male scientists were often positioned within the narrative of eccentric genius, but for a woman to be so is more problematic as there is no tradition of such representation; the feeling is of amusement but without the link to 'greatness'.
[69] Zangwill, p. 9.

human, more personal' – by implication, more 'womanly' out of the laboratory than within it.[70]

Zangwill was not alone in presenting women and the laboratory as an unsettling combination; H.G. Wells has the suitor of his heroine, Ann Veronica, call her experimental equipment and materials 'All your dreadful scientific things'.[71] *The Call* was published in 1924, the year following Hertha's death. The scientific experiences of Ursula in the novel follow closely those of Hertha (although the former's family situation is very different to conform to the requirements of a romantic novel). Passages of Evelyn Sharp's biography echo word for word episodes in *The Call* and Sharp and Zangwill were in correspondence with each other. Sharp's *Memoir* also betrays some ambivalence to Hertha's laboratory, this time from her natural daughter, Edie, who is quoted as complaining 'I do wish mother had a boudoir all filled with yellow satin furniture, instead of a laboratory.... like the mothers of other girls'.[72] In the novel Ursula is a Christian (nominally at least, as the fictional family celebrate Christmas) so Hertha's Jewishness is ignored, despite the fact that the author was married to leading Jewish writer Israel Zangwill (who was, therefore, Hertha's son-in-law). Was this a deliberate attempt to downplay Hertha's Jewish heritage? Or merely Zangwill following the conventions of romantic fiction? (And if the latter, why did Zangwill feel that having a Jewish heroine would contravene these conventions?) It is difficult to assess whether Hertha's ethnicity, once she had renounced Judaism on her marriage, played any part in her later marginalization from male scientific networks. Certainly, for Tattersall and McMurran, Hertha's 'Jewish background does not seem to have affected her social or scientific life',[73] yet it is difficult to determine the inner motivations of those who chose not to include her. It will be suggested in chapter seven that Hertha's prominent Jewish features, especially in her later years, may have led to her identification with the threatening image of the 'black widow', a representation used to question women's rationality, especially that of older 'militant' women fighting for female suffrage (a cause with which Hertha was publicly associated).

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[70] Ibid., p. 131.
[71] Wells, p. 196. There is a further interesting subtext to this as the (unsuccessful) suitor is constructed as unmasculine and foppish because he is not at ease in scientific surroundings, as discussed in chapter three.
[72] Sharp, *Hertha Ayrton*, p. 154.
[73] Tattersall and McMurran, p. 88.

Women's place in science

As the institutionalisation and professionalization of science consolidated in the first two decades of the twentieth century, a place in science, and by extension in the laboratory, was negotiated for the increasing number of women with scientific qualifications. Scholars including Margaret Rossiter and others have demonstrated how women were incorporated into scientific employment and research but were segregated within it to roles that made use of their feminine 'special skills'. These roles were typically low-paid, low-level technician and assistant appointments which worked to reinforce the dominant gender hierarchies in science, not to challenge them. They often required 'great docility or painstaking attention to detail' and writers calling for increased opportunities for women 'glorified these positions, considered them very suitable for women in science, and advocated more of them'.[74] Rossiter locates most of her research in the United States, but similar processes occurred in the UK, accelerated during World War One when women were needed to replace men away on active service. It was during these years that women first gained admission to the National Physical Laboratory, employed in the Metrology Department to undertake gauge-testing, an important aspect of the munitions industry. By the summer of 1917 there were ninety nine women out of 420 staff in the department.[75] It is significant that as considerably more female scientific graduates entered the labour market, so laboratory jobs requiring patience, persistence and a capacity for tedium became 'female'. One researcher of women in the sciences has suggested that this process took place earlier, at the end of the nineteenth century. According to Gould, women became associated with laborious tasks requiring patience, persistence and the ability to remain attentive while dealing with exceedingly routine tasks. Eleanor Sidgwick, who worked with Lord Rayleigh during the 1880s on the determination of electrical standards, typified the kind of work at which women were thought to excel: 'repetitive, routine, well-mannered and aesthetically pleasing'.[76] Although immediately compelling, a gender distinction along these lines as early as the 1880s becomes difficult to sustain when it becomes apparent that men undertook - and were highly praised for - this kind of work.

[74] Margaret W. Rossiter, ' "Women's Work" in Science', in Kohlstedt, pp. 287-304 (p. 289).
[75] National Physical Laboratory, '100 years of the National Physical Laboratory', *Metromnia,* 9 (2000) <http://www.npl.co.uk/npl/publications/metromnia/> [accessed February 5 2005]
[76] Gould, *Femininity and Physical Science in Britain*, p. 139.

Precise measurement was becoming increasingly important to science, an approach led from the mid-nineteenth century by William Thomson (Lord Kelvin) at the University of Glasgow[77] and adopted later by Cambridge physicists at the Cavendish under the leadership of Lord Rayleigh. Isabel Falconer has demonstrated that nearly all the experiments undertaken at the Cavendish were 'finicking and difficult to perform' calling for patience and tenaciousness from all researchers.[78] Certainly this was true for Rayleigh/Sidgwick's experiments to derive standards for the Ohm. These were conducted late at night to avoid magnetic and other disturbances, Rayleigh regulated the speed, Dr Schuster took the main readings and Eleanor Sidgwick recorded the readings of the auxiliary magnetometer. Equipment consisted of an electrically-driven tuning fork and a circularly-calibrated card attached to a spinning coil to confirm that the rotational speed coincided with the frequency of oscillation of the tuning fork. A critical feature of the experiment was the speed control for the rotation of the coil; a secondary needle was introduced to monitor the effects of changes in the direction of the Earth's magnetic field.[79] When Dr Schuster left Cambridge, his part of the work passed to Sidgwick, while hers went to various volunteers, including her sister and once to her brother, Arthur Balfour. The division of duties here was not made along gender grounds. Important criteria for assuming responsibility for taking measurements was possession of scientific knowledge and aptitude for teamwork, based in this case on familial relations. Rayleigh's son remembered that the glass blower at the Cavendish had only limited scientific knowledge and was therefore not qualified to take responsibility for experimental readings or for making numerical reductions.[80] Moving away from the Cavendish, Peter Broks has written that 'patience' and 'perseverance' were bywords for scientific practice in the late Victorian and Edwardian era, used to describe scientists of the day to such an extent that they 'verged on cliché'.[81] Such frames of reference were not used solely by journalists; Rayleigh praised John Kerr for his discoveries in electro-optics 'accomplished under no small difficulties by courage and perseverance' and the journal *Nature* praised William Crookes for the

[77] See Graeme Gooday, 'Precision measurement and the genesis of physics teaching laboratories in Victorian Britain', *British Journal for the History of Science*, 23 (1990), 25-51 (pp. 29-36).
[78] Isabel Falconer, 'J.J. Thomson and "Cavendish Physics" ', in James, The *Development of the Laboratory*, pp. 104-117 (p. 106).
[79] Humphrey, 'Lord Rayleigh', p. 10.
[80] Rayleigh, *Life of J.J. Thomson*, p. 25.
[81] Broks, p. 44.

‘extreme care and pains’ that he took in making weighings’.[82] What is significant here is that around 1900, the signification and meaning of laborious and painstaking work changed according to the sex of the researcher who performed it. By the end of World War One, routine, 'finicky' work was largely the preserve of women.

At the turn of the nineteenth century, there were few female researchers and the whole practice of science, and its significations, were still in the process of being negotiated. In this fluid and changing situation, women did not yet have a fixed, prescribed role in the laboratory. The experimental facility was presented as a masculine place with an abrasive culture, symbolic of the manly virtues of bravery, persistence and fortitude, and femininity was not included in this image. However, this is not to deny that some of the women who entered the laboratory extended existing ideas of women’s service to the work that they performed there. William Crookes’s wife was said to be delighted to help him when she could, often carrying out weighings for him in his chemical work which ‘as she said, was suited to the delicate fingers of ladies’.[83] Crookes did most of his experimental work in his home laboratory, so his wife did not need to leave the domestic sphere and working alongside her husband could be presented as a natural extension of her wifely role.

Conclusion

As historians of science and gender have illustrated, the accelerating professionalisation of science at the end of the nineteenth century did pose an effective barrier to women's participation. Hertha found obstacles throughout her life which made it difficult for her to sustain an identity as a professional scientist like her many male peers. However this process operated in a more complex way than just the closing of institutional doors to women. Justification and naturalisation of women's varying exclusion from the laboratory required the propagation of a masculine laboratory culture - both actual and mythic - which emphasised the physicality of the experimental space and the dangers that could lurk there. The creation of an heroic identity for scientific experimenters also served a useful function in elevating their moral and material worth at a time when the authority and status of their profession

[82] Lord Rayleigh, 'Presidential Address', p. 240; P. Zeeman, ‘Scientific worthies: Sir William Crookes, F.R.S., *Nature*, 77 (November 7 1907), 1-3 (p.1).
[83] Rayleigh, 'Reminiscences', p. 237.

was being established. It is interesting to note that the experimental and physical sciences were, at this time, removed from nature to the laboratory while, in contrast, sciences such as botany and geology continued in addition to seek phenomena as they occurred in nature. Women have been associated with the natural biological sciences while becoming virtually invisible in the physical ones: that the laboratory was configured as an unsuitable place for a woman may have contributed to this gender divide.

Figure 5.1
Source: Rayleigh. 'Reminiscences', facing p.226

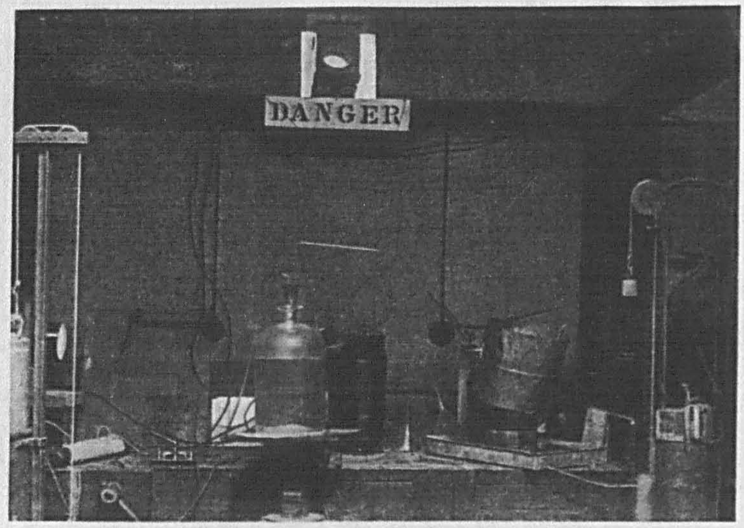


Figure 2. The Physical Laboratory, Royal Institution. Apparatus for concentrating argon.

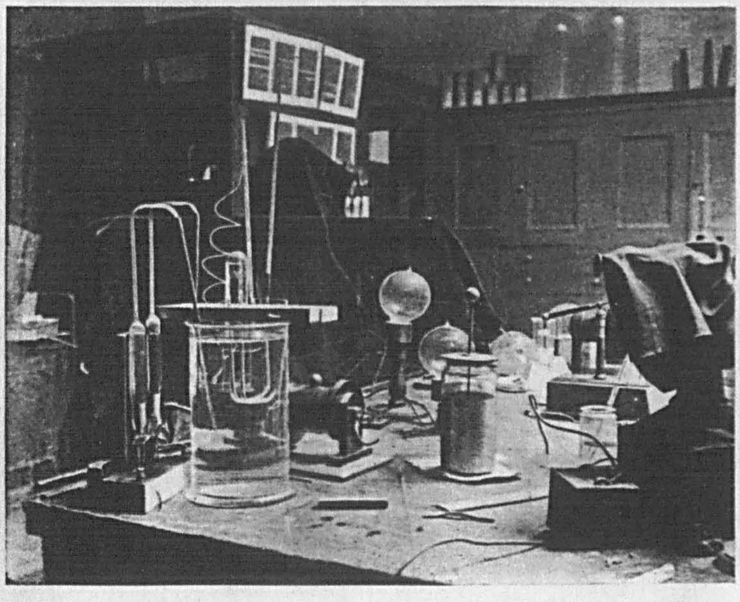
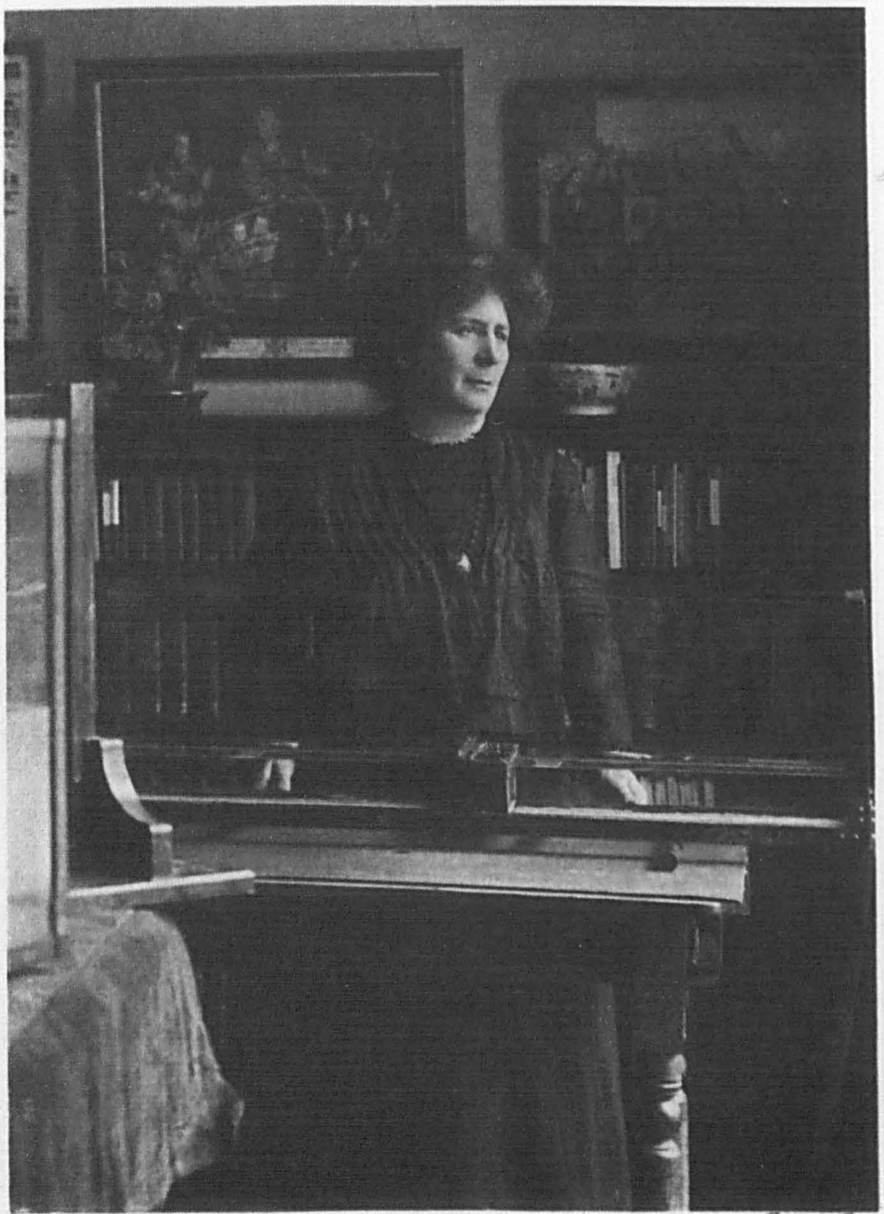


Figure 3. The same. Small-scale argon apparatus.

Facing p. 226

Figure 5.2
Source: RSL (Photograph of Hertha Ayrton)



Russell Photo

Mrs Ayrton in her Laboratory.

LONDON: EDWARD ARNOLD & Co

Figure 5.3
Source: Rayleigh, 'Reminiscences', facing p.240

Figure 8. Sir William Crookes in his chemical laboratory.
(Near the end of his life)

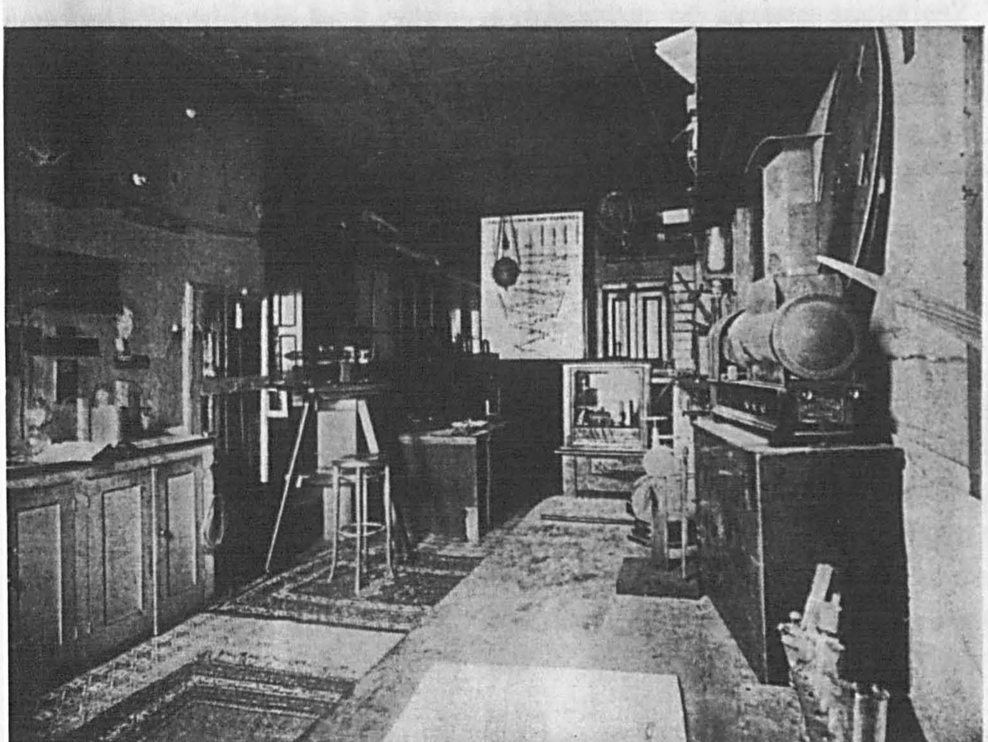


Figure 7. Sir William Crookes's physical laboratory.

Chapter six

The Mathematics of Gender

Women, participation and the mathematical community

When Grace Chisholm Young published a joint paper with her husband in the *Proceedings of the London Mathematical Society* in 1910, she was just the fourth woman to have published there since the journal's creation in 1865. By this time female membership of the London Mathematical Society was around five percent, the majority of whom were women who had connections with the new colleges for women at Cambridge. Both Girton and Newnham had produced a number of notable female 'wranglers' (first-class honours students) in the Cambridge mathematics tripos in the years surrounding 1900, plus a far greater number of women achieving second-class honours. When it comes to assessing the participation of women in mathematics, as these preliminary remarks suggest, whichever variable chosen will depict a differently-focussed account. Should we look at the membership of learned societies? The number of mathematical publications by women? The number of women progressing to the specialist part II of the Cambridge mathematics tripos or gaining a higher degree in the subject? Or the number of female academics in mathematics perhaps? Each of these perspectives will suggest a subtly different picture.

Aims

This chapter will explore the nature and scope of women's involvement in mathematics in the decades surrounding 1900, putting that participation into context and investigating the confluence of conditions that facilitated a female contribution at a time generally held to be sceptical, if not hostile, to female rationality. It will demonstrate that women were accepted into the mathematical community - into academic networks and learned societies - with less hostility than their scientific sisters, and that this was made possible by key differences in practice and culture between the two disciplines. Mathematics did not professionalise in the same way as the practical or experimental sciences and retained a strong tradition of amateur involvement. This opened up opportunities for women that remained closed in scientific communities with a professionalising agenda and members' material, as well as scholarly, interests to promote. Moreover, in seeking its legitimacy from purity and distance from the material world, pure mathematics became less conflicted with contemporary norms of femininity; a process that developed, in part, in response to a masculine culture of bravery and stoicism that emerged around experimental science in the closing decades of the nineteenth century. As material practices differed, so did each discipline's use of language and metaphor, and these new 'colourings' had the effect of naturalising women's inclusion or exclusion. However, despite the mathematical community welcoming women at one level, it excluded them from its highest honours which were regarded as achievable only by men. Fuelled by an emphasis on individual creativity, pure mathematics placed a romantic tradition of genius at centre stage; an ideology which privileged the male mind and ensured that gender-specific hierarchies remained in place even as women were accepted into the mathematical community.

Women and mathematical education

There is no doubt that the growth of higher education for women was a turning point in women's access to higher-level mathematics as the universities enjoyed a near monopoly on providing advanced mathematical education. By 1900 there were a number of institutions in Britain where women could study for degrees in mathematics as well as women's colleges at Cambridge and Oxford. However research opportunities, so fundamental to women's ability to contribute to creative mathematics, were still very limited. For a man, success as a 'wrangler' in the Cambridge mathematics tripos usually led to a college fellowship, eligibility for mathematical coaching work and a continued, intimate connection with the mathematical community of his university. For women, this was rarely such an easy option. The women's colleges did not have the financial benefactors or resources to fund fellowships and lectureships in the same manner as the older, well-endowed Oxbridge colleges and, as a result, the growing number of women students entering British universities was not matched by a commensurate increase in the appointment of women teachers at those institutions.[1] Women's colleges, too, were isolated from the scholarly and power networks that operated within the ancient universities. Female dons and 'graduates' were not awarded degrees or full voting/membership rights on the same terms as the men until 1920 (Oxford) and 1948 (Cambridge)

[1] Dyhouse, *No distinction of Sex?*, p. 134.

and this meant that they had little say in university reforms and were dependent on the goodwill of male dons for providing teaching and, in particular, supervision for research.

Despite the barriers to graduate research for women, by the end of the nineteenth century a small but growing number of female mathematics 'wranglers' had managed to achieve doctorates and university teaching positions. Girtonian Charlotte Angas Scott spent four years as a residential lecturer at Girton while studying for a DSc with Cambridge's leading mathematician, Arthur Cayley. Her doctorate (1885), as her official BSc (1882), was awarded by the University of London as Cambridge did not give degrees to women. Cayley had been a long-time sympathiser with the cause of higher education for women, as outlined in chapter one. Philippa Fawcett, who had famously been placed 'above the senior wrangler' in the 1890 tripos, was awarded a one-year research scholarship at Newnham after which she was appointed lecturer. In 1892 Fawcett was also made a fellow of University College London. Theodora Margaret Meyer lectured in mathematics at Girton from 1888-1918, becoming director of studies in mathematics in 1903; Francis Cave-Brown-Cave followed a similar trajectory, moving from success in the tripos to being a member of staff from 1903-1936. Meyer and Cave-Brown-Cave forged long-term teaching careers at Cambridge but did not make significant contributions to research. Similarly, Fawcett only ever published one research paper and retired after a few years to undertake education/governmental administration; Angas Scott, like so many of Cambridge's top-performing female mathematicians, found it necessary to venture abroad in search of opportunity. At Bryn Mawr College for women in the States she made a marked impact on women in mathematics by supervising several women's doctorates, including that of fellow Girtonian Isabel Maddison. Maddison remained all her life at Bryn Mawr as a lecturer and, increasingly, an administrator.

The small number of women finding opportunities in research and university teaching did not reflect the increasing number of women gaining a high place in the Cambridge mathematics tripos and going on to sit the specialist extension examination taken at the end of the fourth year of study. Women's names were first listed on the annual order of merit in 1882 but, by this time, the tripos was beginning to come under attack by reformers who believed that its highly competitive (and highly public) ranking system was detrimental to the development of mathematics. The next three decades were a time of controversy and change as Cambridge reformers sought to modernise the tripos in an attempt to encourage creative research which, it was argued, was being sacrificed to examination technique as candidates trained solely for a high place on the lists. These pressures resulted in an initial change in 1882 when the examination was divided into part I (four days of examinations) and part II (five days) which were taken a week apart in the summer term after three years of study; it was the results of this that comprised the annual order of merit. Progression to a new, specialist part III, open only to 'wranglers', was taken in the tenth term. In 1886 this was simplified to part I, taken over several days and resulting in placement on the order of merit, followed by the more specialist part II as a separate examination taken by 'wranglers' only. This latter examination enabled candidates to specialise in pure or applied subjects in their fourth year by choosing in advance the division in which they wished to be examined. These changes took place alongside complementary reforms in the natural sciences tripos which led to an increase in its mathematical component and it beginning to rival the mathematics tripos as a key route into laboratory-based science.[2]

The changing relationship between the mathematics and natural science triposes is significant in addressing women's participation in both, as will be discussed below. In 1883 a special provision allowed graduates from the mathematics tripos to proceed directly to the advanced part of the natural sciences tripos and, by end of century, so many were taking advantage of this that the decreasing numbers of men taking the specialist part II of the mathematics tripos became a serious concern to Cambridge's pure mathematicians. By 1900, the natural sciences tripos included higher mathematics and had become a strong examination in its own right. In contrast, a de-emphasis of physics in the mathematics tripos had made that examination less important for physicists. The implications of these developments for the mathematics tripos were made explicit by J.W.L. Glaisher, then president of the London Mathematical Society, when he announced that the 'senior wrangler is displaced from his throne' as he no longer owed his position to the results of the whole examination. As a result, the titles of wrangler, senior optime and junior optime had 'lost their old significance'.[3] Earlier,

[2] For an analysis of relations between the Cambridge mathematics and natural sciences triposes see Wilson, 'Experimentalists among the mathematicians'. Wilson omits women from his analysis.
[3] J.W.L. Glaisher, 'Presidential Address', p. 29. Wranglers were recipients of first-class honours; senior optimes second-class; junior optimes third-class. Glaisher (1848-1928) was a lecturer at Trinity College Cambridge for most of his adult life and a Fellow of the Royal Society; at this time he was a leading figure in the LMS.

on the introduction of these reforms, the *Girton Review* had explained that in order to take part II, a candidate must first pass part I, adding that 'the standard being, however, so absurdly low that Mathematical Honours are notoriously the easiest road to a degree'.[4] The inclusion of women's names - albeit unofficially - on the order of merit from 1882 is usually credited to pressure resulting from the success of Charlotte Angas Scott in being placed equal to eighth wrangler in the 1880 mathematics tripos. However, that women's inclusion had coincided with the introduction of changes that radically reduced the prestige of a top place in the lists made this concession one that was less threatening to grant and, at the same time, turned it into a somewhat pyrrhic victory.

Mistresses of theory? Women on the mathematical pass lists

As already noted, a recent scholarly history of Cambridge mathematics, Andrew Warwick's *Masters of Theory*, provides an exhaustively-researched and gender-sensitive account of the subject which is proving a valuable resource for social historians of mathematics. However, since Warwick's focus is on masculinity, he does not extend his framework of analysis to women or assess in any depth the performance of students at the women's colleges. (And women's names are entirely absent from his appendix listing the top ten wranglers and their coaches to 1909). Warwick remarks that 'women were rarely placed among the top wranglers', yet an analysis of the pass lists reveal that there were eight women from Girton and Newnham placed in the top ten and another three in the top fifteen.[5] These figures do not include the many women placed in the twenties, or Angas Scott's achievement in winning a place equal to the eighth wrangler in 1880, as this was before women were listed formally alongside the men. This omission of women is crucial, not just incidental, as adding women into the equation extends Warwick's examination of the dynamics behind changes in the tripos and poses questions for his argument connecting mathematics, sexuality and manliness in the last decades of the nineteenth century. The following analysis of women's mathematical performance clearly shows that female students may have been peripheral in terms of numbers, but their impact on the prestige, culture and configuration of the tripos was substantial - not least *because* at mid-century the examination was, as

[4] 'The mathematics tripos', *Girton Review*, (December 1882), 3-4.
[5] Tripos results are reproduced in J.R. Tanner, ed., *The Historical Register of the University of Cambridge, being a supplement to the Calendar with a record of university offices, honours and distinctions to the year 1910* (Cambridge: Cambridge University Press, 1917).

Warwick suggests, perceived as so essentially masculine. That women were achieving high positions on the pass lists was a significant factor in the lowering of the prestige and status of the examination, a process that accelerated from the 1880s to the abolition of the order of merit in 1909.

From 1882 the successes of the women's colleges were highly visible, both within Cambridge and beyond, as women's names were now being announced alongside the men's at Senate House and being reported in local and national newspapers such as *The Times*. Reformers of the tripos system centred their arguments on claims that the order of merit encouraged technique at the expense of real mathematics and, to bolster their case, they pointed to women's increasingly good performance as evidence of the examination's shortcomings as an indicator of real, creative mathematical ability. As outlined in chapter one, an important element of contemporary understandings of the female intellect was that women, in the words of a sympathiser with the cause of education for women, 'were quick to catch a point, adept at picking out details .... (but) .... they were undoubtedly inferior to men in their stamina for study and their power of reasoning'. Women were diligent, faithful 'followers' but their lack of originality made it impossible for them to do more than follow in men's footsteps. As a result, the higher one travelled up the educational ladder, the less benefits there were in educating women as the female sex was not capable of great creative work.[6] According to this view, women's success in the tripos could only mean that the examination itself had been (to use a modern term) 'dumb-downed'. Women's success was one factor in pushing the mathematics tripos off its pedestal as the elite degree for men; another was the introduction of part II which marked the beginning of the end of Cambridge 'mixed mathematics' and created the conditions for the growth of pure mathematics as a distinct, separate subject. It will be demonstrated below that women's winning performance in mathematics, and the feminine colouring that this gave to the discipline, was a key factor in enabling the natural sciences tripos to gain status and assume a mantle of masculinity that had once been mathematics' alone.

So what was the performance of women in the Cambridge mathematics tripos? Analysing the data from 1882 when women were first included, to 1909 when the order of merit was abolished, reveals that there were thirty three female wranglers and 385 honours passes at senior optime

[6] Sir Stafford Northcote was speaking in support of the founding of the Girls' Public Day School Company in 1873; see discussion in Burstyn, pp. 70-83.

and junior optime levels from Girton and Newnham. The year that Philippa Fawcett beat the senior wrangler was also notable for producing two Girton wranglers (both placed in the twenties) whose achievements have been inevitably overshadowed. These numbers are not an insubstantial achievement as women suffered the handicap of inadequate preparation and only variable access to top-flight coaching. (See the discussion on coaching in chapter one). At Girton in the early 1880s it was estimated that, at the end of their first year, women students were at much the same point as a fairly well-prepared male undergraduate was when he began his mathematical studies at Cambridge. This situation was expected to improve (and did) by end of century as provision of girls' secondary education grew and 'graduates' from the women's colleges became teachers in new schools, passing on their skills and expectations to the next generation.[7] Significantly, by the 1890s women were keen to sit the more specialist part II of the mathematics tripos. This examination was open (usually - there could be special dispensations) only to 'wranglers', therefore the number of women participating was necessarily small; when Grace sat the examination in 1892 she was the only woman alongside fourteen men. With the growth in popularity of the natural sciences tripos however, the numbers of men entering for part II also diminished and women comprised over a third of all candidates in some years. For example, in 1899 three women and four men passed the part II examination; in 1901 the figures were five and two respectively. In the years that lists are available, twenty four women achieved a pass in this advanced extension examination. Given the diminishing entry of men, a higher proportion of women wranglers proceeded to part II than did their male counterparts.

The mathematics tripos and the natural sciences tripos at Cambridge

A gender comparison of candidates achieving part 1 of the mathematics tripos and the natural sciences tripos clearly shows the latter becoming dominantly masculine in character as women comprise a growing proportion of candidates in mathematics (see the graphs in figure 6.1). Women were also becoming increasingly visible in the natural sciences tripos, due in part to the opening in 1884 of new laboratory facilities to prepare students from the women's colleges for the examination, and also due to the effects of William Bateson's centre for research into

[7] 'The Mathematics Tripos', *Girton Review*, pp. 3-4.

genetics which was largely 'staffed' by women from Newnham.[8] However, natural science, especially physics, was not accepted universally as as suitable for women as mathematics; in the first decade of the twentieth century there were suggestions at Newnham to replace science with domestic science - moves which were dismissed angrily by researchers such as Ida Freund.[9] Despite the increased visibility of women in natural science, the ratio of women to men remained far lower in the natural sciences than in the mathematics tripos. At the same time, the power of the mathematical coach was being curtailed as the university sought to take mathematical instruction 'in-house' with the appointment of college lecturers and the growth of university-wide lecture series.[10] Coaches such as Edward Routh had been the focus of reminiscences and mythologies which centred on the driven competitiveness of their training and the male rivalry that took place in the crowded coaching room.[11] Several male wranglers recalled the weekly 'fights' between students resulting in Routh's public display of mark sheets ranking each of them in order.[12] The slow demise of the coaching tradition and subsequent diminution of this shared male experience helped, along with women's infiltration into mathematics and the rapid adoption of the natural sciences by men at Cambridge, to lessen the link between mathematics and manliness that was so strong mid century.[13] Even if actual numbers of women were sometimes small (specifically in part II) their larger presence proportionally in the mathematics tripos helped to inform a new impression of the examination as one that was more at ease with 'the feminine' than natural science; an impression which, as we have seen, added to doubts about its quality and prestige. This new affinity between pure mathematics and women was not, however, confined to Cambridge. Elizabeth Larby Williams entered the University of London in 1911. She remembers that pure mathematics courses were not in demand and in order to provide a sufficiently large audience there was a combined programme of lectures for students from Bedford, King's and Westfield

[8] See Richmond, 'A Lab of One's Own'; and Marsha L. Richmond, 'Women in the early history of genetics: William Bateson and the Newnham College mendelians, 1900-1910', *ISIS*, 92 (2001), 55-90.
[9] Vickery, p. 155. Newnham' s Ida Freund was a chemist, teacher, and researcher at the Cavendish Laboratory.
[10] Rothblatt, pp. 210-242.
[11] For example see Forsyth, 'Old tripos days'.
[12] Warwick, *Masters of Theory*, p. 236.
[13] For analysis of the link between masculinity and mathematics at Cambridge see Warwick, *Masters of Theory*, pp. 176-226.

Colleges. Even so, the class was barely twenty strong and there were almost as many women as men.[14]

The London Mathematical Society

In 1890, in his presidential address to the British Association for the Advancement of Science, J.W.L. Glaisher stressed the vital role that the London Mathematical Society (LMS) played in keeping the flame of mathematical enquiry alive.[15] The Society was then just twenty five years old, but already it was acknowledged as a leading mathematical organisation, not just in Britain, but within Europe too. For any individual seeking to contribute to research mathematics, a fellowship of this learned body was an important requirement. How receptive was this mathematical community to female involvement? The LMS had been established in 1865 by Augustus de Morgan who was concerned to establish a convivial society to which mathematics could be presented and discussed. Although gender was not specified as a factor in membership, in its early years the Society met in the rooms of the Chemical Society (an organisation that was strongly resistant to female participation) at Burlington House, which was also the home of the Royal Society. It would have been difficult at this time for women to access this 'male' space and, by extension, the LMS itself. In the early 1870s the Society moved to its own premises at Albermarle Street. The aims and practices of the LMS were restated in 1889 and its membership criteria spelt out: the Society was instituted for the promotion and extension of mathematical knowledge, consisted of ordinary and honorary members, and required each potential fellow to be proposed and recommended by at least three ordinary members prior to election by a majority. By this time, the LMS had four female fellows: Charlotte Angas Scott had joined in 1881, as had American Christine Ladd-Franklin. Ladd-Franklin, who had attended Vassar College for women in the States, had connections to the society through J.J. Sylvester who was a past president of the LMS. When Sylvester moved to the States in 1877 to accept a chair in mathematics at Johns Hopkins University, he allowed her to attend his graduate lectures despite the university being closed to women. Ladd-Franklin fulfilled all the requirements for a PhD but failed to achieve the award as doctorates were not granted to women at that

[14] Howson, p. 177.
[15] Glaisher, p.725.

time.[16] Sophie Bryant became a fellow of the LMS a year later in 1882. At that time Bryant was teaching mathematics at the North London Collegiate School while researching her doctorate which was awarded by the University of London in 1884. She is generally held to have been the first woman to receive this honour in England, gaining a DSc in Psychology, Logic and Ethics. Theodora Margaret Meyer joined the LMS in 1888, in the same year that she was appointed lecturer at Girton College. Meyer served as director of mathematical studies at Girton 1903-1918, after which she taught at University College London. During the first world war she devoted herself to war work, carrying out calculations connected with the construction of aircraft.[17]

In order to illustrate the unique nature of the membership of the LMS as compared to other learned scientific societies, it is useful to analyse the records for one particular year. In November 1903, as well as thirteen honorary members, the Society laid claim to 361 ordinary members of which thirteen (nearly five percent) were women. Approaching thirteen percent of the membership were fellows of the Royal Society, forty six members in total. Although the largest occupation group was university teachers, comprising 116 or nearly one third of the membership (including three women) by no means were all LMS fellows mathematicians in any 'professional' sense. Forty school teachers comprised the next largest group, followed by ministers of the Church (nineteen) and barristers/JPs (thirteen). Membership also included civil engineers, a naval instructor, an MP and a mathematical editor and reviewer for *The Times* (Constance Isabella Marks). Forty eight (just over thirteen percent) listed no occupation at all, among them the largest group of women (seven) including Grace. Even the category of university teachers was not dedicated solely to mathematics but included teachers in related disciplines such as astronomy and physics; a large proportion of overseas fellows were also represented in this group. Given the occupational (and geographic) fragmentation of the membership, it is clear that the LMS did not function as a pressure group for any particular professional interests. At a time when other learned societies were refining their membership criteria in order to impose qualification bars, raise professional status, encourage patronage, and gain power and influence in the modern, industrial world, the LMS retained many of the

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[16] Johns Hopkins University finally awarded Ladd-Franklin her PhD in 1926, forty four years after completion of her thesis. See Parshall and Rowe, pp. 239-243.

[17] 'Margaret Theodora Meyer', *Girton Review*, May Term (1924); Girton College, 'Meyer, Margaret Theodora', in *Girton College Register, 1869-1946*, ed. by K.T. Butler and H.I. McMorran (Cambridge: Privately printed, 1948), p. 636.

attributes of a gentler age. One reason for this relative stability was that ways of doing mathematics had not changed significantly over the years: it remained a discipline that was attached to the university, it had not seen a rush from the personal study to new spaces of work such as the laboratory, neither did it require new tools or modern instrumentation. For mathematics a desk, pencil and paper could still suffice. Moreover, no qualifications were stipulated as a necessary requirement for an LMS fellow and admission still depended on the recommendation and vote of existing members. Although the majority of fellows would have sat the Cambridge tripos or have achieved a mathematical degree elsewhere, this was not an indispensable requirement. For example, Mrs Alicia Boole Stott had enjoyed no formal mathematical education at all yet was still elected to the Society.[18]

The liberality of the LMS's election criteria can be contrasted to the Royal Society which had made several reforms to its membership selection procedures during the mid-nineteenth century which were designed specifically to exclude 'amateurs'. By end of century, the Royal Society had consolidated its position as a consultative authority on science issues and its fellows were frequent recipients of government patronage. Many fellows of the Royal Society were strongly resistant to the election of female members, not least as the presence of women among their ranks was perceived as a possible threat to prestige and professional status. Similar fears were also central to the hostility to women which manifested itself within the Chemical Society, a body which had been formed by chemists in 1877 expressly in the interests of their profession. The Royal Astronomical Society was similarly jealous of its professional status and influence and many of its fellows felt that this could be questioned if women were admitted. When Elizabeth Iris Pogson Kent of Madras University was nominated as an ordinary fellow in 1886, and the Society's legal adviser found no bar to her election, the governing council was quick to find another opinion. The second lawyer concluded that those who had written the Royal Astronomical Society charter had not intended to allow women and, as a result, Kent's nomination was withdrawn.[19] At a time when the amateur-professional

[18] Alicia Boole Stott was largely self-taught and publication of her mathematical papers resulted from her correspondence with a mathematics professor in the Netherlands who shared her interests. She was the daughter of George Boole, Professor of Mathematics at Queens College Cork, who had died when she was four years of age. H.S.M. Coxeter, 'Alicia Boole Stott (1860-1940)', in *Women in Mathematics*, ed. by Lynn M. Osen (Cambridge MA: MIT Press, 1974), pp. 220-225.

[19] Peggy Aldrich Kidwell, 'Women Astronomers in Britain, 1780-1930', *ISIS*, 75 (3) (1984), 534-546 (p.538).

distinction was seen as increasingly important to a learned association's power and influence, and when the Royal Society, Royal Astronomical Society and others (see chapter seven) were taking steps to formalise women's ineligibility, the acceptance of women into the LMS can be seen as significant.

Despite the visibility of female fellows, the actual number of women members of the LMS was small in real terms (just thirteen at turn of century) and this, in part, reflected the Cambridge dominance of the Society. In 1903 at least nine of the thirteen female fellows had 'graduated' from the Cambridge mathematics tripos. The other women were Alicia Boole Stott, an independent scholar, Constance Isabella Marks, a mathematical editor with a degree from University College London, and Lilian Janie Whitley, a lecturer in mathematics at Westfield College. But it was not just among women that Cambridge had a strong showing; the presidency and council of the LMS was heavily biased to the University in the two decades surrounding 1900 with at least eight of the ten presidents during this time (each holding office for two years) being products of the Cambridge mathematics tripos. The character of the LMS at the end of the nineteenth century was conveyed in the opening remarks to the Society of one president who stressed that he had 'the honour to address gentlemen who, for the most part, have benefited from the congenial associations and scientific air of the ancient universities....'[20] Women were accepted with courtesy by the gentleman members of the LMS 'club', but their participation was not of an equal nature. Women did not gain a presence on the council of the LMS until the appointment of Mary Cartwright who served as the first (and so far only) woman president between 1961 and 1963.[21] Women did not win Society medals, the first female recipient of the LMS De Morgan medal was (again) Mary Cartwright in 1968. William Young won this prestigious medal in 1917, awarded in his name alone despite his wife's key contribution to his papers.

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[20] Samuel Roberts, 'Presidential Address', *Proceedings of the London Mathematical Society*, 14 (1882-3), 6-12 (p.6).

[21] Mary Lucy Cartwright, 1900-1998, gained her doctorate at Oxford and was appointed lecturer at Girton in 1935, becoming Mistress 1946-60. In 1947 she became the first female mathematician to be elected to the Royal Society; she won the Royal Society Sylvester Medal in 1964 and the LMS De Morgan medal in 1968. Her subject was the theory of functions, her work making a contribution to the development of chaos theory. Shawnee L. McMurran and James J. Tattersall, 'Mary Cartwright, 1900-1998', *Notices of the American Mathematical Society*, 46 (2) (1999), 214-220.

Women were, however, active to a certain extent in presenting papers before the Society and publishing in the *Proceedings.* Sophie Bryant achieved a first with a paper on the geometrical form of cell structures which was read to the Society in 1885 and subsequently published in full. Two years later she read another paper on a different subject, but this time did not publish. Bryant was followed by Francis Hardcastle and Mildred Emily Barwell, both Girton 'graduates' who had passed the specialist part II of the Cambridge mathematics tripos in 1892 and 1896 respectively. Bryant and Barwell (at least) had read and discussed their papers before the Society in person as these discussions are recorded in the minutes. Barwell read a paper before the Society again two years later while Ernest W. Hobson, who had coached 1890's top wrangler Philippa Fawcett, was in the chair. By turn of century then, just three papers authored by women had appeared in the *Proceedings of the LMS.* The following decade of the 1900s is initially puzzling as, despite the number of women fellows, the *Proceedings* published no papers by women during this time. Women were participating from the margins however; in 1907 Alicia Stott attended a meeting of the Society in person and exhibited a collection of mathematical models and there were also three communications received from women during this time. In 1910 Grace and her husband published two joint papers and these were followed in 1911 by a first paper by Hilda Hudson, research fellow at Newnham, and another by Marjorie Long, Assistant in Mathematics at Bedford College, University of London. Hudson contributed two papers again in 1912; in 1913 Miss R.E. Colomb published a joint paper with Harold Hilton, Professor of Mathematics at Bedford College. Add to this another joint paper by Grace and William Young and this makes a total of eight papers by women published in the *Proceedings* up to 1914.

Given the female membership of the LMS at this time, this low level of authorship requires explanation. It is difficult to explain the paucity of female authors by any gendered participation pattern as the actual number of men publishing papers was, in relation to the number of male fellows, similarly low. Because of its prestige and international reputation, the *Proceedings of the LMS* acted as an outlet for a small elite of (mostly) Cambridge-connected mathematicians who repeatedly published in the journal, with up to four or five papers authored by the same person in any one volume. For example, William Henry Young had six substantial papers published in 1910 alone, and he was joined in the same volume by fellow Cambridge mathematicians G.H. Hardy and E.W. Hobson who published two papers each. Most fellows of the LMS, male or female, were passive members comprising an audience for the elite mathematicians whose work they read in the *Proceedings* and discussed at meetings. In this light, women's publication record appears less disappointing, and it is important to remember that Grace's contribution was invisible in the vast number of papers published under her husband's name alone.

It does appear, however, that as the *Proceedings* were dominated by a Cambridge clique, once women had moved on from Cambridge they were less likely to publish in the journal, even if they remained active in research. For example, Charlotte Angas Scott, although a life member of the LMS and a productive paper writer, did not contribute to the Society's *Proceedings*. Many of her papers were published in the *American Journal of Mathematics* of which she became co-editor in 1899. Angas Scott also published in the *Transactions of the Royal Society of London* in 1893 and 1894 and in other British and foreign journals. Hilda Hudson, on the other hand, remained at Cambridge and was a presence in the *Proceedings* with three papers between 1910 and 1912. Hudson was one of a Cambridge mathematical family, her father had taught at the University and was later professor of mathematics at the University of London. Hudson had attended Newnham College where she was placed equal to the seventh wrangler in the 1903 tripos (her sister Winifred been placed equal eighth in 1900) and in 1904 had achieved a first-class pass in part II. Hudson followed these Cambridge successes with a year at the University of Berlin before returning to Newnham College to take up a post as residential lecturer, later research fellow.[22] It seems that membership of the LMS was a necessity for any female (or male) research mathematician, but publication could be elsewhere. Other significant journals for the publication of mathematics at this time were the *Quarterly Journal of Pure and Applied Mathematics*, the *Messenger of Mathematics* and, to a lesser extent, the *Proceedings of the Cambridge Philosophical Society*. The *Proceedings of the Royal Society* were also a possible outlet and this will be examined in the succeeding chapter.

[22] Hudson also spent 1912-13 in Bryn Mawr with Professor of Mathematics there Charlotte Angas Scott. At the outbreak of World War One she joined the Civil Service to undertake work for the Air Ministry on applied probability problems associated with aircraft. She published a well-received book on Cremona Variations in 1927. Newnham College, 'Hilda Phoebe Hudson, 1881-1965', *Newnham College Roll Letter* (1966), 53-54.

The Cambridge Philosophical Society

At the inaugural meeting of the LMS in 1865, De Morgan spelt out who its main rivals would be and why the formation of this new society was necessary. The Royal Society, he argued, was 'too wide' and the Cambridge Philosophical Society 'too local'; this, he implied, left a gap for a mathematical society to cater for the specific needs of mathematicians in Cambridge, the universities and beyond.[23] By the time De Morgan was speaking, the Cambridge Philosophical Society already had a long history at the University having been founded in 1819. Its *Proceedings*, which embraced the mathematical and physical sciences, had been published since 1843. Membership of the Society was restricted to Cambridge fellows therefore women were ineligible, but in 1876 new articles of membership had been formulated to allow non-Cambridge graduates to become associates and attend meetings. A history of the Cambridge Philosophical Society, published in 1969, is somewhat defensive regarding the position of women within these new rules and claims that women could be admitted as associates and that, by 1914, they had been 'for some years as a matter of routine'.[24] However, from an analysis of the Society's *Proceedings* in which membership lists were regularly published, there seems little evidence to support this claim. For example, in 1907 the Society had 334 fellows, nine associates, twenty council members and thirty seven honorary members - all male. No women are listed as being admitted until 1914 when Marie Curie was granted an honorary fellowship. Prior to awarding her this honour, the Society had taken advice as to its legality and were reassured that since honorary fellows had no rights, the Society's bye-laws would not be infringed.[25]

No mathematical papers by women appear in the *Proceedings of the Cambridge Philosophical Society* up to 1914, around which time the journal slowly came to be dominated by the biological and physical sciences. Papers authored or co-authored by women in these disciplines, mostly from William Bateson's research group at Newnham or the few female researchers at the Cavendish Laboratory, begin appearing from 1890 onwards. By 1914 twenty five papers authored or co-authored by women had been published, prior to this a smaller number of

[23] Augustus De Morgan, 'Presidential Address', *Proceedings of the London Mathematical Society*, 1, (1865-1866), 1-4.
[24] A. Rupert Hall, *The Cambridge Philosophical Society: A history, 1819-1969* (Cambridge: Cambridge Philosophical Society, 1969), p. 66.
[25] Ibid., p. 66.

communications by women had been noted. All of these papers had been communicated by a male fellow so it is difficult to ascertain if women were ever actually present in person. However, the Society held its meetings at various locations throughout the University and some of these venues were more welcoming to women than others. Whereas women could be a regular presence at the Cavendish Laboratory or botany school, as a general rule they were not admitted into the university chemistry laboratory (until 1909), the medical schools or the comparative anatomy lecture room - all venues used by the Cambridge Philosophical Society to hold their meetings.

Publishing opportunities

A more viable alternative for mathematical women seeking publication was the *Quarterly Journal of Pure and Applied Mathematics* (*QJPAM*) which was not connected to any learned society. Although founded in 1857, from the early 1870s it had been published by Longmans publishers. The first editorial team included Cambridge's Arthur Cayley and this strong Cambridge connection continued with, for example, J.W.L. Glaisher and A.R. Forsyth on the editorial team from 1895. There was also a considerable overlap of personnel with the Cambridge-dominated editorial board of the *Proceedings of the LMS.* An examination of papers in the *QJPAM* reveals twelve papers by women between 1893 and 1914, including four papers by Grace published jointly with her husband and one published under her name alone. Other female contributors were Charlotte Angas Scott, Isabel Maddison, Hilda Hudson and American Florence E. Allen. If the *QJPAM* contained a Cambridge bias in its editorial team, so did the *Messenger of Mathematics*, despite its founding as a journal to encourage scholarship from students new to mathematical research at the universities of Oxford, Cambridge and Dublin. By the beginning of the second series in 1872, the *Messenger* was inviting scholarship from the 'foremost mathematicians of the age' as well as seeking to be a 'stimulus to research in junior students', emphasising that contributions were not restricted to the universities but could come from any source. Despite this, Cambridge scholars dominated this first collected volume of the monthly journal with twelve papers by Cayley, Glaisher and Routh alone. This Cambridge dominance continued well into the next century, with J.W.L. Glaisher serving as editor from 1887 to the outbreak of World War One. Glaisher also edited *QJPAM* and served as president of the LMS 1884-1886. William Henry Young was a regular contributor here, but women were not well represented with just two small contributions up to 1914.

Women did make a significant contribution, however, to the *Educational Times* which was edited from 1902-1918 by LMS fellow Constance Isabella Marks. This monthly journal, established in 1847 and published from 1861-1947 as *The Educational Times and Journal of the College of Preceptors*, carried a popular section devoted to mathematical problems and their solutions as well as notices of scholarships, teaching vacancies and other educational subject matter. Tattersall and McMurran have found that one third of all articles submitted to the *Educational Times* mathematical department under Marks' editorship were by women. The most active time for female contributors was the last decade of the nineteenth century when the majority of female contributors were 'graduates' of Girton and Newnham Colleges. Hertha made the largest contribution, making 117 submissions between 1881 and 1899; other women submitting material included Philippa Fawcett, Isabel Maddison, Francis Cave-Brown-Cave, Margaret Meyer and Hilda Hudson - all (except Hertha) fellows of the LMS. This journal was not a peripheral or specifically amateur outlet; other mathematicians to appear on its pages included Felix Klein, Augustus de Morgan, J.J. Sylvester, Arthur Cayley, James Clerk Maxwell and others. The *Educational Times* was also the outlet for the first mathematical publications by G.H. Hardy and Bertrand Russell.[26]

The above analysis suggests that mathematics in England in the decades surrounding 1900 comprised a small community of amateur and university mathematicians. This community was dominated by a narrow elite of mainly Cambridge scholars who were active in publishing papers, serving as editors on various journals, and sitting on the council of the LMS. Mathematics continued to be attached to the university and did not professionalise or modernise its working practices as did other scientific disciplines during this time. As a result, women were able to move from university mathematics to publishing research papers and becoming fellows of the LMS without facing the same level of hostility than was the case in the physical sciences. This was in part because of their prior university connections (the majority of women active in mathematics were 'graduates' of Girton and Newnham) and partly because mathematics retained a strong 'amateur' flavour. Women

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[26] Jim Tattersall and Shawnee McMurran, 'Women and the Educational Times': <*http://www.math.csusb.edu/faculty/mcmurran/hpm.doc*> [accessed February 5 2005]

mathematicians were not perceived as a threat to mathematics' professional status (as they were seen as threatening to the 'manly' culture of the laboratory) nor were they in competition with men for jobs as they were limited to teaching at the new colleges for women in the UK and in the States. The numbers of women becoming fellows of the LMS and publishing research papers is small in real terms but can be seen as historically significant in percentage terms: the relatively high proportion of female fellows of the LMS in the early 1900s was matched again only in the 1970s.[27] What made mathematics an attractive option for Grace and her female colleagues at the turn of the nineteenth century and were there other factors influencing women's participation in this community?

A growing female affinity with mathematics

In 1898 Professor E.B. Elliott, President of the LMS, felt it necessary to make a plea in his outgoing address for the importance of mathematics and mathematical training. Elliott was dismayed at the growing loss of students to the natural sciences tripos and the consequent 'numerical weakening' of mathematical candidates which, he argued, 'should be striven against with all our energies'. His defence of his discipline, which was made just two years before the start of the twentieth century, centred not on the utility of mathematics or any service that it could render to society, instead it referred back to the older tradition of mathematics as a crucial part of a 'liberal education' designed to encourage moral and intellectual capabilities:

> We believe a sound mathematical training to be of such value in mental development .... (that) .... life-long application to mathematical investigation, on the part of those who prove to be qualified for it, is a noble use of the human mind, a devotion to the pursuit of truth in a field where the human intellect is on sure ground.[28]

As discussed with reference to women's mathematical training at Girton in chapter one, the purpose of a liberal education was not to prepare the student for any specific role in the world, or to provide any kind of professional training, instead the individual and his or her personal

[27] Memberships lists of the LMS reveal that in 1905 fourteen women comprised 5.5% of membership; this is a higher percentage than is the case for 1970 when just 5% (48) of members were women. Claire Jones, 'Grace Chisholm Young: gender and mathematics around 1900', *Women's History Review*, 9 (4) (2000), 675-692 (p. 679).
[28] E.B. Elliott, 'Some secondary needs and opportunities of English mathematicians', *Proceedings of the London Mathematical Society*, 30 (1898-1899), 5-23 (p. 15).

development (in terms of self-discipline and character formation) was the priority. In the closing decades of the nineteenth century, the growth of physical mathematics and technology, with their emphasis on learning about the world and creating new methods of controlling it, had eroded the argument that mathematics, as part of a liberal education, was best pursued for its own sake and to aid the mental cultivation of the individual. Cambridge men were now deserting the mathematics tripos for the natural sciences with, for Elliott and his colleagues, alarming speed. By end of century the notion of a liberal education was retained by pure mathematicians, in the absence of any justification of their subject on the grounds of utility, as one way to legitimise their discipline.

The ideal of a liberal education was also used by advocates of higher education for women as a powerful argument to promote their cause. As James Orton wrote in *The Liberal Education of Women*, mathematics (and the classics) 'tend to enlarge and strengthen the moral and intellectual powers, and this is necessary *sub modo* for women as well as for men'.[29] His point was that higher education would help women fulfil their potential as wives and mothers, rather than seduce women away from these roles as feared by opponents of the new experiment in female education. This argument was in part a pragmatic response to assuage the fears of conservatives, it was also a reflection of the influence of reformers such as John Ruskin and Charles Kingsley who urged that improved education for women was the prelude to their exerting a higher moral authority within the family and in the schoolroom.[30] In short, a liberal education was best suited for women and mathematics, with its long association with these ideals, was an appropriate and comfortable choice. Moreover, mathematics was less likely than laboratory work to compromise a woman's femininity or to threaten feminine propriety with unwholesome knowledge of the world. On the contrary, with its traditional connection to the development of moral character and good sense, mathematics could be the ideal tool to prepare women for their role as society's - and men's - superior conscience.

The changes in the conception and configuration of mathematics that gave the discipline an affinity with women did not rest solely on its

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[29] Orton, p. 198.

[30] Rita McWilliams-Tullberg, 'Women and degrees at Cambridge University, 1862-1897', in *A widening sphere: Changing roles of Victorian women*, ed. by Martha Vicinus (Bloomington: Indiana University Press, 1977), pp. 117-145 (p. 145).

advantages in imparting a liberal education. As has already been outlined in chapter four, pure mathematics became more 'feminised' in its use of terminology at turn of century, especially in relation to Göttingen-style analysis. The abstraction and moral integrity of this mathematics was increasingly conveyed by the use of language that was feminised and romantic. The language of 'elegant' theorems or 'beautiful' proofs contrasted sharply with that often applied to experimental science which could call for 'courage', 'perseverance' or 'iron nerve' (as discussed in chapter five). This 'feminine' language of aesthetics helped legitimise this 'useless' mathematics (for example set theory, the main focus for Grace and her husband, dealt with mathematical objects that were an intellectual creation manipulated in imaginary, many-dimensional space). It also helped distinguish pure from practical mathematics, the latter seeking its justification from its usefulness in the world. In this way, the differing language and metaphors of feminised pure mathematics and robust, masculinised science, worked to naturalise each discipline's separate practices of inclusion or exclusion.

At the same time in England, there developed a tendency for intellectual work in general to be viewed as feminine as a rugged, athletic manliness with anti-intellectual tendencies gained ground.[31] This was reflected at Cambridge by a dilution of the connection between mathematics and rigorous bodily training, a flow of men from the mathematics to the natural sciences tripos, and the introduction of a new end-of-century stereotype: the anti-intellectual, sports-motivated 'university hearty'.[32] That 'brain work' could be viewed as particularly feminine was implied by James Orton in a passage quoted in chapter three. Orton argued that, in many respects, the sedentary student life was more natural to women than to men; men were now increasingly at the vanguard of physical science and engaged in leading the way in the growth of new technology.[33] In this way, Orton and others upended older ideas about women's incapacity for rational thought (which, as discussed in chapter five, had been endorsed by the new Darwinian sciences and projected on to experimental science) and argued that mathematics, art, classics and similar scholarly pursuits could be the natural preserve of women.

These conclusions contrast with Warwick's arguments connecting mathematics to manliness which he sees as lasting into the twentieth

[31] Heathorn, pp. 467-468.
[32] Warwick, *Masters of Theory*, p. 224
[33] Orton, p. 39.

century, although he does suggest ways in which this association changed in tone during the last two decades of the nineteenth century. Warwick is not centrally concerned with pure mathematics as represented by figures such as Young and Hobson, or later Hardy and Russell; his analysis centres instead on the earlier tradition of 'mixed mathematics', the break-down of which facilitated the rise of the new 'pure mathematics'. However for this study, which focuses on the decades around 1900, it has been necessary to explore the growing distinctions between 'masculine' practical mathematics and the 'feminine-friendly' pure in order to uncover the significance and role of women mathematicians. In contrast, Warwick's attention is on figures such as Maxwell and Larmor, mathematicians who applied their findings in the laboratory, a space which, as was illustrated in chapter five, had become a site of manly exhibition. The historical changes that occurred within mathematics, the discipline's fragmenting nature, and the contrasting constructions that developed around the pure and the practical, are crucial to an understanding of the gender distinctions that affected women mathematicians around 1900.

The Pure and the Practical - significations beyond mathematics

Central to views about the appropriateness of various disciplines to either sex was the idea that there is a fundamental difference between pure mathematics and practical mathematics and science. It has been a scholarly tradition to classify women mathematicians with women scientists but, as this study shows, there was a marked contrast in the material practices of science and mathematics and, at varying historical periods, key differences in what each discipline signified. Change was especially fluid at the end of the nineteenth century and it influenced the way in which each discipline was perceived as desirable for which sex. As a result, subsuming women mathematicians with women scientists runs the risk of losing sight of these differences - differences that can be key to an understanding of women's participation. There is no doubt that a clear separation was made at this time between pure and more practically-oriented mathematics; indeed the difference between the two was seen as important enough to provide the theme for J.W.L. Glaisher's 1890 Presidential Address to the British Association for the Advancement of Science. Glaisher's speech was a rallying cry for pure mathematics which he saw as under threat by the accelerating growth of 'physical mathematics'. Although Glaisher did not seek to undervalue 'those branches of mathematics which we owe to the mathematical necessities of physical inquiry' he followed this by creating a hierarchy between the two which clearly privileged the pure:

> But it always appears to me that there is a certain perfection, and also a certain luxuriance and exuberance, in the pure sciences which have resulted from the unaided, and I might also say inspired, genius of the greatest mathematicians which is conspicuously absent from most of the investigations which have had their origin in the attempt to forge the weapons required for research in the less abstract sciences.[34]

Glaisher's arguments parallel the debates going on in Germany at this time and presage the remarks of English mathematician G.H. Hardy who contrasted 'uncontaminated' pure mathematics with the ugly utility of the applied. In England as in Germany, pure mathematics was fighting to retain its prestige in the face of mathematical physics and the practical sciences which were assuming the status and influence which had once been the preserve of mathematics alone. Glaisher used other familiar arguments to legitimise and add moral value to his discipline: that pure mathematics was the only way to reveal certain truth and that pure mathematics, dependent as it was on the creativity and power of individual minds, was the natural home of genius. He finished by broadening his remarks to include society in general, implying a lament for the old established order and warning that the 'search after abstract truth for its own sake, without the smallest thought of practical application or return in any form..... are signs of the vitality of a people, which are among the first to disappear when decay begins'.

Glaisher's conception of pure mathematics was unashamedly elitist. Only special individuals were equipped with the necessary mathematical aptitude and even they required years of study to learn the language and acquire the necessary expertise. This combined emphasis on the power of the individual intellect (a mathematician working in inspired isolation with his brain, not his hands) and a language requiring special skill, imposed 'of necessity .... narrow limitations on the members of our audience'. There was also a class dimension here: Glaisher's words rehearsed the long-standing recognition of the 'higher' moral worth of 'brain-work' over 'hand-work', and by claiming pure mathematicians as a 'natural born' elite he effectively discounted the possibility of infiltration via education by any 'lower' intellectual ranks of society. Pure

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[34] Glaisher, p. 725.

mathematicians were unanimous in their fears that their specialism was losing out to 'physical mathematics' and, as a result, they were more inclined to accept elite women with the necessary expertise in order to bolster their numbers and strength. However this acceptance was tempered by an admiration for, as Glaisher put it, the 'inspired genius of the greatest mathematicians'. This referred back to a romantic ideology of genius with which Victorian thinkers were fascinated. According to this tradition, the genius was born with a natural gift endowed by Nature - a condition which was inextricably linked to the masculine. Any attempt to apply genius to women, given the gendered history and derivation of the concept, inevitably invoked a tension, as discussed in chapter two. In England as in Germany, romantic ideology, with its feminine colouring yet intrinsically masculine core, privileged the male mathematical mind and ensured that gender hierarchies remained in place even as women were welcomed into the mathematical community.[35]

Conclusion

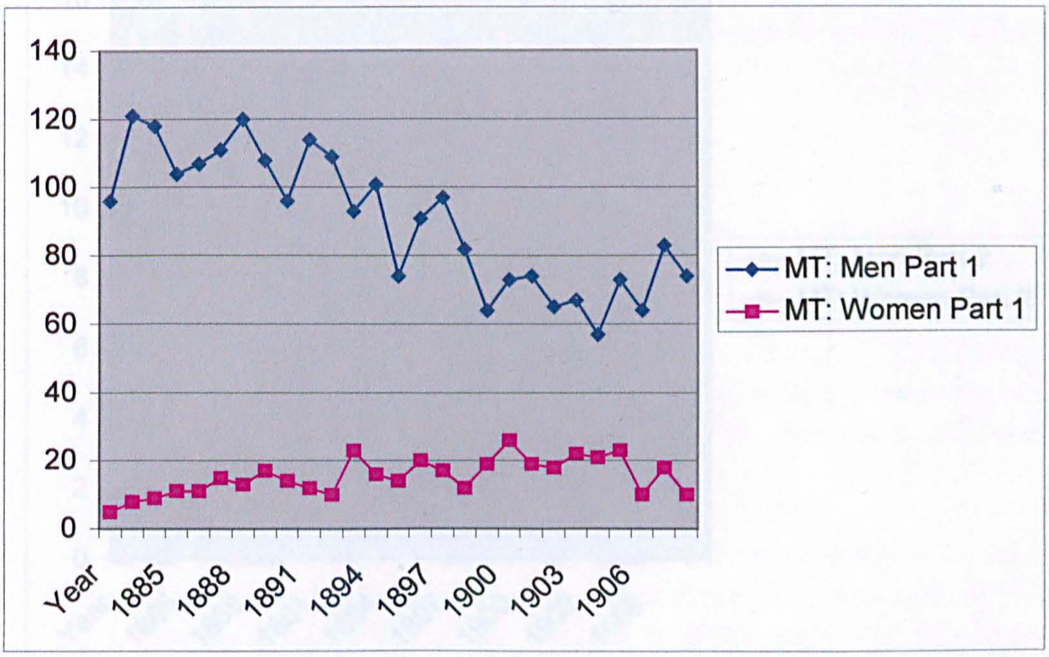
Historians have pointed to the long-standing connection between masculinity and rationality on the one hand, and femininity and the emotions on the other, exploring how these dualities have led to the exclusion of women from mathematics (and the sciences). Mathematics was believed 'unnatural' for women as it required a level of abstract thinking that was beyond feminine capabilities. Without seeking to deny these connections, it is important to recognise the historical nature of mathematics and gender, and how relations between the two, including the intellectual resources drawn upon to propagate them, change and develop over time. It has been illustrated how during the nineteenth century Romanticism continued but mutated; William Whewell's objections to algebraic analysis, voiced early in the century, echo Glaisher's defence of the very abstraction that his predecessor most feared.

At the end of the nineteenth century the nature and meanings of mathematics and science were being contested just as the movement for suffrage and higher education were questioning what were acceptable roles for women. Physical mathematics and laboratory science became

[35] Warwick, *Masters of Theory*, effectively demystifies this mythology of genius by illustrating how Cambridge's mathematical training imparted mathematical skills and successfully reproduced its mathematical elite.

increasingly professionalised and represented themselves as manly pursuits, fully engaged in the world and capable of 'mastering' it. These disciplines were 'manned' by the new scientific professional - professionals who were concerned that any overt hint of femininity could undermine their growing status (as will be demonstrated with a contextualisation of Hertha's career in the following chapter). In contrast, pure mathematics fled from the world into abstraction, legitimised itself through romantic notions of genius and the mystery of 'great intellects', and, as Glaisher implied, clung to older ideas of a natural born elite whose altruistic talents guarded against 'decay'. Such ideas, in the case of Grace and her husband, led to anti-feminist doubt over women's potential for genius and sympathy with an eugenics based on inherited intellect. At this time of fluidity and negotiation, as mathematics became less conflicted with femininity, and pure mathematicians' numbers decreased, women were accepted into the shrinking mathematical community (albeit up to a point) as pure mathematics became configured as a suitable pursuit for the new, elite, educated gentlewoman.

Figure 6.1



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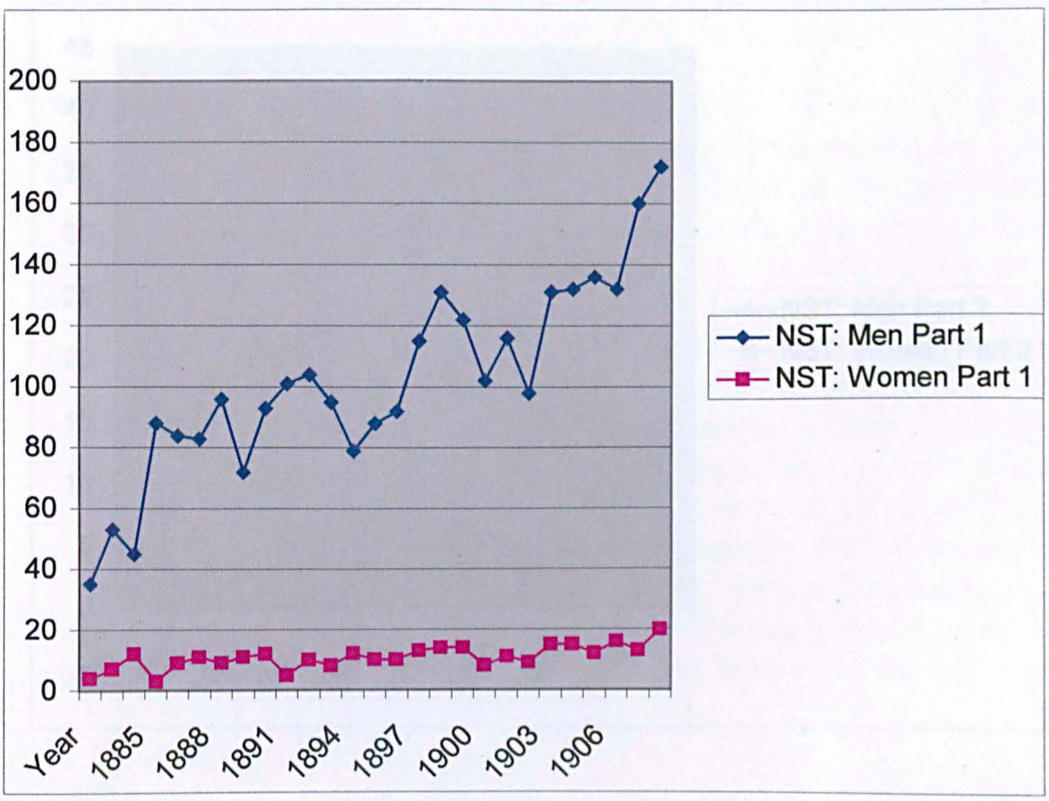

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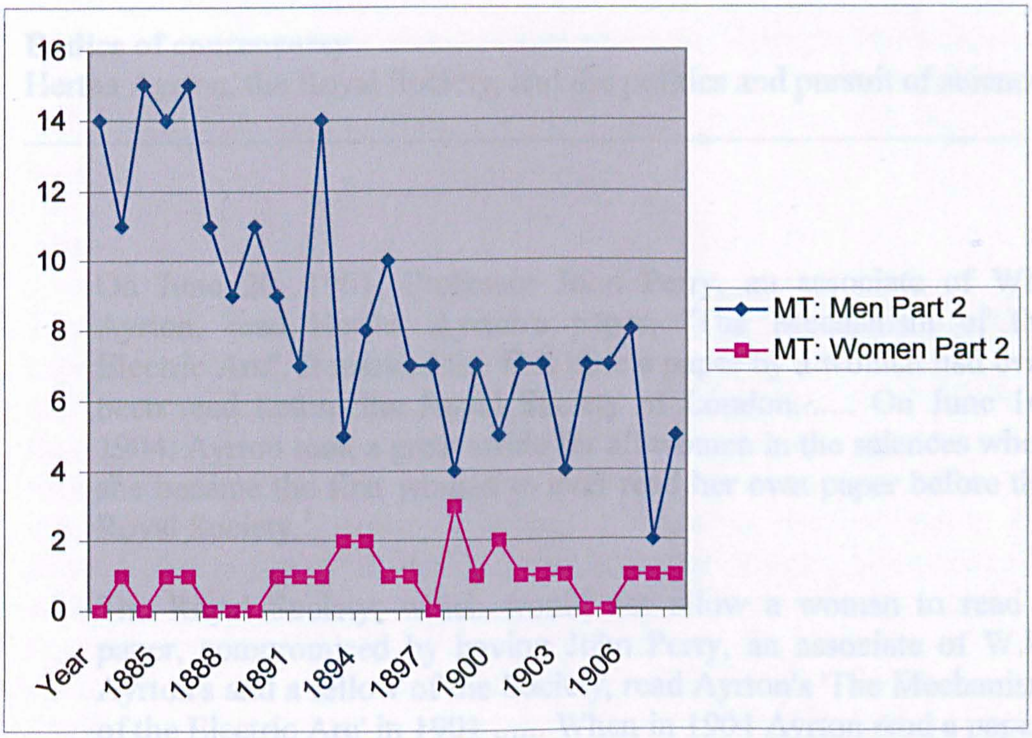
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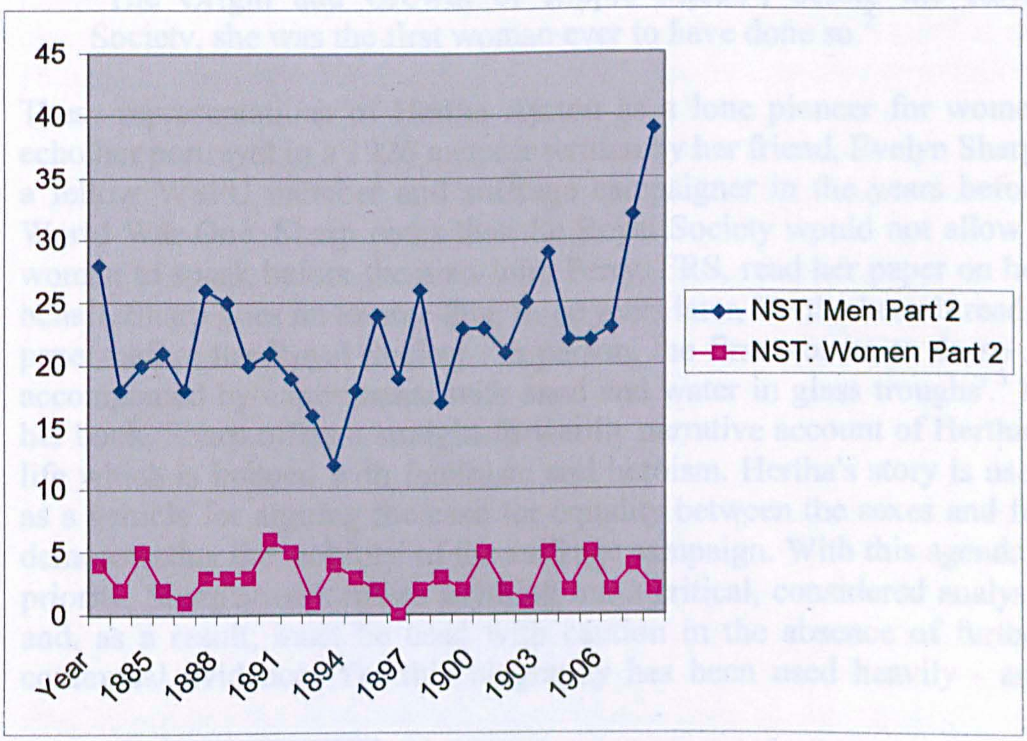
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Chapter seven

Bodies of controversy

Hertha Ayrton, the Royal Society, and the politics and pursuit of science.

> On June 20, 1901, Professor John Perry, an associate of Will Ayrton, read Hertha Ayrton's paper, "The Mechanism of the Electric Arc". It marked the first time a paper by a woman had ever been read before the Royal Society of London....... On June 16, 1904, Ayrton took a great stride for all women in the sciences when she became the first woman to ever read her own paper before the Royal Society.[1]

> The Royal Society, which would not allow a woman to read a paper, compromised by having John Perry, an associate of W.E. Ayrton's and a fellow of the Society, read Ayrton's 'The Mechanism of the Electric Arc' in 1901 ...... When in 1904 Ayrton read a paper, "The Origin and Growth of Ripple Marks", before the Royal Society, she was the first woman ever to have done so.[2]

These representations of Hertha Ayrton as a lone pioneer for women echo her portrayal in a 1926 memoir written by her friend, Evelyn Sharp, a fellow WSPU member and suffrage campaigner in the years before World War One. Sharp notes that the Royal Society would not allow a woman to speak before them so John Perry, FRS, read her paper on her behalf. Sharp goes on to note that, three years later, Hertha herself read a paper before the Royal Society 'in person, the first woman to do so ... accompanied by experiments with sand and water in glass troughs'.[3] In her book, Sharp offers a straight-forwardly narrative account of Hertha's life which is imbued with feminism and heroism. Hertha's story is used as a vehicle for arguing the case for equality between the sexes and for demonstrating the 'nobility' of the suffrage campaign. With this agenda a priority, Sharp's work offers anything but a critical, considered analysis and, as a result, must be used with caution in the absence of further contextual evidence. Yet this biography has been used heavily - and

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[1] Tattersall and McMurran, p. 101 and p. 103.
[2] Ogilvie, p. 33.
[3] Sharp, *Hertha Ayrton*, pp. 150-170.

unproblematically - as source material by several scholars seeking to illuminate women's achievements in science. In the worthwhile attempt to recover and celebrate female achievement, such simple 'breakthrough' narratives, as typified by Sharp, distort the position of women in science and, to a certain extent, misrepresent women's relations with the Royal Society.

Aims

This chapter seeks to build a more accurate picture of Hertha's experiences, considering them within the context of the social, science and gender politics of the time, and demonstrating that the difficulties facing women in science were very different from those experienced by women seeking admittance to the mathematics community. This will involve an analysis of the procedures, politics and motivations of the Royal Society - the context within which Hertha's successes were made - which reveals a far more complex story than just one woman 'breaking through' entrenched institutional misogyny. The discussion will commence with a consideration of women's relationship with the Royal Society, assessed from a number of perspectives including papers published by women and women's involvement in Royal Society conversaziones. Close attention will be paid to the Society's award of the Hughes Medal to Hertha in 1906 and to the discussions and negotiations surrounding her nomination to a fellowship in 1902. It will be illustrated that Hertha's failure to gain entry to the Royal Society had a direct impact on her credibility and on her work. Yet the Royal Society was not wholly anti-women: assessing and arbitrating on the work of the increasing number of female scientists emerging from the expanding colleges for women was essential to the Society in its aim to remain the 'gatekeeper' and 'judge' of elite science.

The Royal Society and female 'firsts'

Hertha Ayrton was not, in fact, the first woman to have her work read before the Royal Society. Mathematician Mary Somerville's paper, 'On the Magnetizing Power of the More Refrangible Solar Rays', was presented to the Society by her husband in 1826 and published in the *Philosophical Transactions*.[4] Women's papers were appearing in both the *Philosophical Transactions* and the *Proceedings of the Royal Society*

[4] Ogilvie, p. 163.

well before Hertha's paper on the electric arc was published in 1901. The earliest paper by a woman has been identified as Ann Whitfield's who wrote on the effects of a thunderstorm in Rickmansworth, Hertfordshire, in 1760.[5] At the end of the eighteenth century astronomer Caroline Herschel published several papers, including one detailing the discovery of three nebulae. This latter paper was highly commended by the Royal Society, which took the rare step of formally announcing Herschel's discoveries by letter to astronomers in Paris and Munich.[6] It would have been difficult for the Society to do this if her discoveries had not been put before the fellows. Although numbers are small compared to male authors, contributions by women to Royal Society journals increased during the final decade of the nineteenth century, not least as students in natural and morphological sciences at the new women's colleges made their presence felt. For example, in 1894 alone chemist Emily Aston published two papers in the *Philosophical Transactions*, while the *Proceedings* published papers by Philippa Fawcett, then a researcher at the Cavendish Laboratory, and Catherine Raisin, geologist; the latter's paper co-written with Thomas Bonney. Raisin is credited as sole author of a second paper published in 1898. In the previous decade, Alice Johnson and Lillian Sheldon (who both worked at the Balfour Biological Laboratory at Newnham) had contributed papers and several women received joint credit for collaborations. These included astronomer Margaret Huggins (with her husband William) and Eleanor Sidgwick (with Lord Rayleigh) whose papers were read before the Society on May 4 1882 and January 11 1883. The new century saw yet another 'rush' by women, including a flurry of papers co-authored by various female researchers and Karl Pearson, Professor of Applied Mathematics and Mechanics at University College London.[7] In the volume of the *Proceedings* in which Hertha Ayrton's abstract on sand ripples was published (vol. 74, 1904-5) there were five papers published by women.[8]

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[5] Dwight Atkinson, *Scientific discourse in sociohistorical context: The Philosophical Transactions of the Royal Society of London, 1675-1975* (London: L. Erlbaum, 1999), fn. p. 102 (the only discussion of gender is relegated to this footnote).

[6] Schiebinger, p. 263. German-born Caroline Herschel (1740-1848) discovered eight comets in the closing years of the eighteenth century and her reworking of John Flamsteed's observations, *Catalogue of Stars*, was published by the Royal Society in 1798.

[7] In 1891 Karl Pearson co-founded the science of 'biometrics' which applied statistical analysis to evolutionary research, following Francis Galton's methods. Pearson employed a number of female mathematicians in his Biometrics Laboratory (established 1903) and Eugenics Laboratory (established 1907) including Mary Beeton, Cecily Fawcett, Alice Lee and Martha Whiteley. See Magnello, 'Part 1', pp. 87-90; Rosaleen Love, 'Alice in Eugenics-Land: Feminism and eugenics in the scientific careers of Alice Lee and Ethel Elderton', Annals of Science, 36 (2) (1979), 145-158.

[8] Dorothy Bate (geologist); Florence M. Durham (geneticist); Alice M. Waller; Francis Cave-Brown-Cave (mathematician); and Hertha Ayrton.

Around this time women were increasingly within the pages of other scientific journals too, including the *Proceedings of the London Mathematical Society, Nature, Philosophical Magazine* and the *Proceedings of the Institution of Civil Engineers.*[9] These are modest gains and it is important not to over estimate female participation, however it is clear that Hertha Ayrton was not alone in pushing at the door of the Royal Society. Although for the most part the door held fast, cracks appeared - and a few determined women were quick to find their way in.

Hertha's claim to have been the first woman to read a paper before the Royal Society in person is more tenable. All papers put before the Society by non-members, whether male or female, were required to be 'communicated' by a fellow, with typically a third of papers received in this way each year. A Royal Society Yearbook spelt out the procedure explicitly: the communicating fellow was obliged to ascertain that the paper was 'fit and proper' whereon, according to the nature of the paper and other circumstances, the reading may consist of the title alone being read by one of the secretaries, the paper being read by the author or secretary in part or in whole, or the author may be invited to give an oral exposition of contents, with experiments. On June 16 1904, there were fifteen other papers on the agenda for that afternoon as well as Hertha's, including one by fellow Girton mathematician, Francis Cave-Brown-Cave. At the previous week's meeting a paper by geologist Dorothy Bate had been read and, later in the year, Florence Durham's paper on the skins of pigmented vertebrates was one of five papers read before the Society on December 1st. In the absence of other evidence, it is difficult to ascertain whether any of these women, or indeed those which had gone before them, spoke in person. The Royal Society yearbooks, council minutes and journals do not state whether authors were present in person at the meeting in which their papers were read, so other corroboration is required. Hertha's presence can be verified by the details of John Perry's submission when he nominated her for the Hughes Medal and from Hertha's correspondence with Joseph Larmor, council secretary.[10] Referees had challenged Hertha's experimental findings and she had been allotted just ten minutes on June 16th to show an

[9] For a comprehensive list, see Mary R.S. Creese, *Ladies in the Laboratory? American and British Women in Science, 1800-1900: A survey of their contributions to research* (London: Scarecrow Press, 1998).

[10] Joseph Larmor (1857-1942) was lecturer and (from 1903) Lucasian Professor of Mathematics at Cambridge.

experiment to counter these objections.[11] Presenting this event as 'a great stride for all women in the sciences' as Hertha became 'the first woman to ever read her own paper before the Royal Society' is, in its implications, somewhat misleading. This representation conjures up the image of a woman presenting her research findings in entirety before her audience - the fact was rather more prosaic: a ten-minute presentation (and justification) of an experimental procedure among an afternoon schedule of fifteen. Hertha's paper was still not entirely accepted and just a short, revised abstract of it appeared in the *Proceedings* in March 1905.[12] The larger paper was not published in its entirety, in revised form, until 1910.[13] At some twenty plus pages long, reading the whole of this to the Society would have taken considerably longer than ten minutes. Hertha's papers were read before the Royal Society on six occasions: 1901 (on the mechanism of the electric arc); 1904, 1908, 1911, 1915 (on the formation of sand ripples); and 1919 (on a new method of driving off poisonous gases). By the end of the decade, women were permitted as a matter of course to attend the meeting at which their paper was read.

The celebration of Hertha as an exceptional female presence at Royal Society conversaziones also requires contextualisation. The Society held two conversaziones at their premises in Burlington House each year; the first in May was colloquially named 'the black one' as, explained *The Times* on May 10 1900, 'it was exclusively confined to the sombre sex' with exhibits that 'would appeal to the specialist'. The second conversazione of the year, held in June, was generally known as 'Ladies Night' and reported in the press as a society function. Characterised as 'less severely scientific',[14] this offered refreshments as well as scientific entertainment, with tea and coffee served in the Officers' Rooms and wines and ices on the ground floor. It was at these 'Ladies Soirees' that Hertha participated, her first appearance being on June 21, 1899, when she displayed her experimental apparatus in the library alongside twenty two other exhibits. Although she was the only female exhibitor on this occasion, the following year Annie Maunder displayed her photographs of the Milky Way and, in 1904, Hertha's illustration of the formation of

[11] RSL, Letter 04029 (Hertha Ayrton to Joseph Larmor, Royal Society, June 12 1904).
[12] Mrs Hertha Ayrton, 'The Origin and Growth of Ripple Mark', *Proceedings of the Royal Society of London, Series A*, 74 (1905), abstract, pp. 565-566. Communicated by Prof. W.E. Ayrton, FRS, Received April 21; Revised May 26, Read June 16 1904.
[13] Mrs Hertha Ayrton, 'The Origin and Growth of Ripple-Mark', *Proceedings of the Royal Society of London, Series A*, 84 (1910), 285-310.
[14] RSL, Scrapbooks (*The Times*, May 10 and June 22 1900).

sand ripples was joined by Mrs D. H. Scott's display of new techniques in photography showing the movements of plants. Women then, although rare, were not entirely absent at the periphery of the Royal Society. Similarly, women's names can be found as recipients of Royal Society grants - Minutes of Council show awards being made to Dorothy Bate, Miss Elles and Edith Saunders. Presenting Hertha Ayrton as an exceptional woman engaged in a lone project to challenge Royal Society patriarchy is an inversion of the male 'hero' narratives that successfully distorted women's participation in science for so long. The situation at the turn of the nineteenth century was more fluid and certainly more complex. The interesting question to explore is why the Society dallied with women at its margins yet was (and is) wary of accepting them in any formal, explicit way.[15]

Politics in the Fellowship

When John Perry proposed Hertha Ayrton for a Royal Society fellowship in 1902, the receipt of her certificate of candidature presented the council with a dilemma that touched on more than just the Society's relationship to women. Hertha's nomination also served to foreground questions about the Society's position in relation to other learned societies and raised issues surrounding its standing and status both within science and the wider governing class. For the Royal Society, the key mechanism that gave self-identity, status and prestige was the selection of its fellows. Who should be eligible for nomination and how their election should take place had occupied the Society from almost its earliest days and, during the nineteenth century, moves had been made to limit membership and enhance exclusivity. The role of 'amateurs' and 'dilettantes' was successfully curtailed in 1847 by a revision of statutes which included restrictions on eligibility, number of nominees and election procedure. In previous decades just a third of fellows had been scientists, the rest using the Society as an exclusive club. Now only

[15] The Royal Society's latest (2004) fellowship figures reveal that out of 1272 fellows, 57 (4.5%) are women. Debate over 'bias' within the Royal Society was fuelled in the press in April 2004 by the leaking of the information that Oxford pharmacology professor Susan Greenfield had been nominated but rejected for a Royal Society fellowship. Around 1900, the idea of female fellows was abhorrent to sections of the Royal Society who believed that women would trivialize and lower the Society's status. In language reminiscent of this, in 2004 one fellow was reported as letting it be known, anonymously, that Greenfield's election would be an 'insult' and two fellows, anonymously, threatened to resign: Tim Radford, 'The Guardian profile: Susan Greenfield', *Guardian*, April 30, 2004,< http://www.guardian.co.uk/uk_news/story/0,,1206419,00.html> [accessed February 5 2005] Like Hertha, Susan Greenfield was also the recipient of a Royal Society medal; she had been awarded the Faraday Medal in 1998.

proven scientists could be nominated and they needed the support of six, instead of three, fellows. A limit on numbers was also introduced, a change which ensured that only one election took place each year and that no more than fifteen new fellows were elected. The power of the president and council was enhanced significantly as the task of recommending the names to be put forward for election was placed in their hands. Not surprisingly, the number of men vying for election greatly outnumbered the number of fellowships available and this was a factor in the comparatively slow infiltration of 'commercial men' into the Royal Society. It was not until the second decade of the twentieth century that professional scientists comfortably outnumbered the gentleman amateurs thanks to the development of electricity and other new technologies.[16] At the time of Hertha's nomination, involvement in commercial enterprise could, by raising the question of self-interest, still taint a researcher's work and imply conflict with the aims of the Society. As William Huggins reiterated in his 1903 presidential address, the unique position of the Royal Society among other academies had been reached '.... by its unwearied pursuit of truth for truth's sake without fee or reward'.[17]

Huggins's implied criticism of fellows who worked not out of ideals of service, but for profit, reflected a fault line within the Royal Society and could have been aimed directly at the 'modernisers' who had put forward Hertha's name the previous year. Of the fellows who signed her nomination, John Perry worked with William Ayrton providing technical education and developing commercial applications at the Central Institute. The other signatories were William Preece, who was chief engineer at the Post Office and had introduced wireless telegraphy to that organisation; William Tilden, chemistry professor at the Royal College of Science, a partner institution of the Central at South Kensington; Raphael Meldola, professor of chemistry at Finsbury Technical College and member of the Society of Chemical Industry; William Abney, an astronomer and photographic chemist who served on the Board of Education and was a member of the Society of Chemical Industry; George Carey Foster, a physicist/chemist who had just been appointed Principal of University College London; Olaus Henrici, a physicist who lectured at the Central for the mathematics and mechanics department and held a chair at Bedford College London; Joseph Everett, physicist

[16] Jonathon Rose, *The Edwardian Temperament*, 1895-1919 (Ohio: Ohio University Press, 1986), p. 120.
[17] Huggins, p. 40.

and Norman Lockyer, astronomer and editor of *Nature*. Both Lockyer and Cary Foster were noted for their sympathy with women's causes. Lockyer supported the admission of women to learned societies in his journal; Cary Foster had been one of the pioneers of the 'London Ladies' Educational Association' which had led to the admission of women to London University in 1878.[18] Royal Society President William Huggins was bitterly opposed to Hertha being elected a fellow - it was during his presidency too that she was nominated and, in 1906, awarded the Hughes Medal. On the latter occasion Huggins wrote to Joseph Larmor, Secretary to Council, blaming his cold for preventing him from taking the Chair that day and implying that, had he been present, he would have obstructed award of the medal.[19] Huggins had co-authored several astronomical papers with his wife Margaret, but their collaboration was not presented to the world as an equal partnership. As noted in chapter four, Barbara Becker has demonstrated how the couple colluded to present a traditional and romanticised image of themselves with William as the principal investigator and Margaret his loyal and gifted assistant.

Huggins's antipathy to scientifically-presumptuous women, and to commercialism, found a joint target in the controversial person of Hertha Ayrton. Hertha's research on the electric arc had led to patents for applications to streetlights, searchlights and cinematography, so she too was a worker at science's technical and commercial fringe. For a male scientist, this raised questions regarding the objectivity of his work. For a woman, it also transgressed ideals of feminine service and defied the assumption that respectable, middle class women did not receive payment for their work. The relationship between science and technology was hierarchical yet fluid at the end of the nineteenth century and one of the functions of the Royal Society, achieved via the selection of fellows and acceptance of papers, was to police and maintain this divide. Huggins and Joseph Larmor, who regarded William Thomson/Lord Kelvin's commercial interests as distractions from the proper intellectual pursuits of a natural philosopher,[20] represented the elitist ideals of an old guard for whom the taint of commercialism and the challenge of the professional men (and possibly women) represented a threat to the status of the Royal Society, the status of science - and the status quo. A similar clash of class and ideology was being played out at

[18] Mason, 'Hertha Ayrton and the admission of women', p. 207.
[19] RSL, Letter 948 (William Huggins to Joseph Larmor, November 2 1906).
[20] Crosbie W. Smith and Norton M. Wise, *Energy and Empire: A biographical study of Lord Kelvin*, (Cambridge: Cambridge University Press, 1989), p. xix.

Cambridge, another institution facing an influx of the middle classes and adaptation to meritocracy. Here, the infiltration of rational, secular, scientific ideas was challenged by dons who, by promoting the late-Victorian concept of the 'ether', championed non-material interests and the 'imagination' as opposed to the 'cowardly security' of sense data.[21] In line with romantic ideology, such an approach privileged 'innate ability' over 'acquired skill' and served to set limits as to who was eligible to participate in scientific discovery. (It is no surprise therefore that pure mathematicians Grace and William Young were scathing in their criticism of materialist scientific theory, arguing, for example, that the views of Thomas Huxley and John Tyndall were 'crude' for holding 'that everything could be explained by means of mechanical, chemical, electrical etc. laws'.[22]) The struggle being played out at the Central for reputation and status for technical education and engineering (described in chapter three) was brought by its protagonists to the Royal Society. These pioneers of technical training for the professional middle classes were attempting to repudiate the notion that practical labour was inferior to intellectual labour, and to democratise science by opening it up to more than just a 'natural born' elite. In this light, Hertha's proposed fellowship can be interpreted as part of a larger battle for the soul of science; her nomination another tool in the moderniser's armoury of strategies to promote change.

The Culture of the Royal Society

Just as sections of the Cambridge elite clung to metaphysical concerns in the struggle against change, so the Royal Society carved a self-identity and cohesiveness based on a history, language and rituals that were all exclusively male. Creating a continuity between existing fellows and the natural philosophers who had established the Royal Society in the seventeenth century was key to this process. At each meeting of the Society and council, the mace, presented by Charles II, was still placed on a table in front of the president; in addition, all new fellows were required, as their earliest predecessors had been, to sign the charter book (this practice is still current today). In 1857 the Society had moved to Burlington House in Piccadilly - a palatial mansion (now housing the Royal Academy of Arts) which, like the Royal Society itself, had its

[21] Brian Wynne, 'Natural knowledge and social context: Cambridge physicists an the luminous ether', in Barnes and Edge, pp. 212-231 (p.217).
[22] LUSA, Young Papers, D140/35/11 and D140/35/18 (mathematical notes and autobiographical notes).

origins in the 1660s. In 1873, transferral to the specially-refurbished East Wing had provided ample space to display the many portraits, busts, statues, medallions and other relics that were in the possession of the Society. These reminded fellows of their heritage and reinforced their consciousness of being one of a highly-select group of men. The only representation of a woman was a bust of Mary Somerville that was placed in the great hall in 1831. It was to be over one hundred years later before a woman was admitted in person to such a privilege; the first female fellows were not elected until 1945.[23] When *World Magazine* profiled Sir Michael Foster, secretary to the Royal Society, at his rooms in Burlington House, special reference was made to him being 'surrounded by objects associated with the great pioneers of science'.[24] Amongst portraits and statuettes of Darwin, Cook, Newton and Humboldt, there was a vast oil painting that took pride of place above the fireplace. This depicted the president and members of the council of the Royal Society waiting upon Michael Faraday, asking him to accept the office of president. This image of scientific 'apostolic succession' - a religiosity recalling classical paintings of Christ and his disciples - was enhanced by a number of relics and instruments retained by the Society. These included a lock of Newton's hair, two rules purportedly made from the wood of his apple tree, and a cast of his face taken after death. Such imagery also hinted at a male asceticism, long associated with intellectuality, which was important at a time when rationalism was being challenged by the rise of movements such as decadism and spiritualism.[25] Maintaining ritual reminiscent of the Christian church may also, for some fellows, have been a way of maintaining a comforting continuity and structure after their religious faith had been successfully challenged by Darwin. Recalling the male-centred practices of the clergy, it certainly presented another obstacle to women being accepted in the similarly all-male community of the Royal Society.

Two other institutions to which many Royal Society fellows belonged reinforced this male exclusivity: the Athenaeum Club and the Royal Society dining club. Upper middle class males could be uncomfortable around women, their lives being structured around institutions (boarding school, Oxbridge colleges, the Regiment) where women were rarely

[23] Crystallographer Kathleen Lonsdale and microbiologist Marjorie Stevenson.
[24] RSL, Scrapbooks (*World Magazine*, September 17, 1901).
[25] Eagleton argues that Victorian reason started to crumble in the 1890s as the 'high-rationalist subject of Mill or Middlemarch imploded into Madame Blavatsky and Dorian Gray': Terry Eagleton, 'The Flight to the Real', in Ledger and McCracken, pp. 11-21 (p. 11).

present except in roles such as maids, matrons or cleaners.[26] In 1911 such unease was articulated in a book arguing that, in the interests of courtesy, gentlemen cannot tell ladies that they are wrong, therefore meaningful intellectual discussion between the sexes is impossible.[27] Earlier similar sentiments had been ridiculed by Edwin Abbott in his satire *Flatland*: 'among Women, we use language implying the utmost deference for their Sex... but behind their backs they are both regarded and spoken of as being little better than mindless organisms'. Abbott also alluded to the 'double-training' given to children with boys being removed from their mothers and nurses at the age of three to be taught a new 'vocabulary and idiom of science'.[28] Abbott may have had his tongue firmly in his cheek, but Almroth Wright, FRS, was wholly serious when he suggested in *The Times* in 1912 that men can only do their best work when free from 'the onus that all differential treatment imposes'.[29] Situated just around the corner from the Royal Society and long associated with it, the Athenaeum's namesake was the ancient Roman centre for the study of literature and science. Many fellows (including Grace's husband) patronised this gentlemen's club which offered a seamless passage for men of science from one comfortable and select all-male environment to another.

Many of the elite of the Royal Society also held ambitions to join the Society's dining club. Unlike the president and secretaries, fellows had no automatic right to membership but had to be proposed in writing by three 'diners' and then elected, with at least a three-quarters majority, by the some sixty or more members. The rules of the club give an insight into how a late nineteenth century male network of patronage and power worked in practice. Each ordinary member had the privilege of inviting one male guest to dine each year and visitors included foreign men of science, civil servants, MPs and members of the government. It was a mechanism by which the Royal Society could extend its influence and gain status over other learned bodies. For example, fellows were often seconded to government commissions, therefore the letters 'FRS' after your name could be a gateway to a government-funded management position. In 1902 the new National Physical Laboratory was put under Royal Society control and Richard Glazebrook, FRS, was appointed

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[26] Helen Kanitkar, ' "Real true boys": Moulding the cadets of Imperialism', in *Dislocating Masculinity: Comparative ethnographies*, ed. by Andrea Cornwell and Nancy Lindisfarne (London: Routledge, 1994), pp. 184-196 (p.185).
[27] Hamerton, pp. 263-264.
[28] Abbott, p. 50.
[29] Sir Almroth Wright, 'Militant Hysteria', *The Times*, March 28 1912, Letters to Editor.

director. In the same year Glazebrook was also elected to membership of the Royal Society dining club.

This segregation of the sexes, which so dominated the habits of the Royal Society, was predicated on a gendered conception of science that conceptually, and effectively, removed any notion of femininity from the public practice of science. The sexual metaphors of Baconian science, the construction of woman as object/nature, and man as the virile subject/penetrator of her secrets, are familiar and often rehearsed.[30] This representation of women as the object of enquiry (but never the active enquirer) infused the ideals of the seventeenth-century founders of the new natural philosophy - ideals of which fellows in the nineteenth century were constantly reminded by the iconography and language of their surroundings. It is also important to remember that the first fellows explicitly sought to create an unambiguously separatist, 'masculine science', based on a new materialist vision, in order to differentiate themselves from alchemy, a practice which still provided an alternate and competing model of nature. In the latter tradition, matter was believed to be suffused with spirit and both male and female principles were necessary for understanding. While the central image for the new mechanical philosophers was man subduing and controlling a female nature, the alchemists made metaphorical use of images of coition, the merging of male and female and the conjunction of mind and matter. Paracelus wrote that a man without a women is not whole - for him the sexes were (allegorically if not in reality) equal.[31] The commitment to a 'masculine philosophy' heralded a start to femininity being regarded as not different, but inferior, a trope reiterated in the Darwinian theories of the late nineteenth century.

In a preface to his 1903 Presidential Address, William Huggins emphasised the Royal Society's status in relation to the new societies by characterising it as 'The Mother Society' and the newer bodies as her 'daughters'.[32] Such characterisation was not atypical; it was used again when the Royal Society was praised as 'the Mother and Model of all the

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[30] The classic statement of this position is Carolyn Merchant, 'Isis' Consciousness Raised', in Kohlstedt, pp. 11-22; also Fox Keller, pp. 7-8 and 78-80; Ludmilla Jordanova, *Sexual Visions: Images of gender in science and medicine between the eighteenth and twentieth centuries* (Wisconsin: University of Wisconsin Press, 1993), pp. 87-110.
[31] Fox Keller, pp. 43-65.
[32] Huggins, p.ix.

learned societies in the English speaking world'.[33] Given the Royal Society's early emphasis on masculine science, feminine iconography did not flourish in English science,[34] so this later representation of 'mother' and 'daughter' societies is interesting. It has parallels with the 'mother' Church - a 'mother' society with its own priesthood of ascetic men of science and its own secular rituals (as outlined above). This type of terminology was also prevalent in freemasonry. A newly established lodge was the 'daughter' of an older 'mother lodge' and the male lodge members identified themselves as 'brothers'.[35] This type of language and metaphor can also be interpreted in the context of an Edwardian glorification of the role of motherhood amidst controversy over sex roles, a declining birth rate and the rise of the eugenics movement. Either way, the implication is that a woman's role is to give birth: to facilitate the acquisition of knowledge, not to produce it herself. So, at the Tercentenary celebrations of the Royal Society in 1912, while the Dean of Westminster Abbey assured fellows and international delegates that 'through the pre-eminent influence of the men of the Royal Society ... Reason, as the noblest gift of God to man .... (will continue) .... the passionate search for the secrets of truth',[36] women were preoccupied with more prosaic tasks. A 'Committee of Ladies' was formed to provide entertainment for wives accompanying delegates. The meeting room at the Royal Society was put aside for their use, and here they waited to be of service, wearing different coloured badges to indicate which languages they spoke.

The 'irrational' face of femininity

If these women offered a comforting image of womanhood to many fellows of the Society, the similarly-dressed, predominantly middle class suffragettes - who were engaged in increasingly militant agitation for the vote around 1912 - must have inspired exactly the opposite. Many of the most violent confrontations of the suffrage campaign took place literally around the corner from the Royal Society, including fierce confrontation with the Police at Buckingham Palace, suffragettes chaining themselves to railings and 'rushes' on Parliament. On November 18th 1910 Hertha was involved in 'Black Friday' when protesters, marching on the

[33] Royal Society, *The celebration of the 250th anniversary of the Royal Society, July 15-19, 1912* (London: Royal Society, 1913), p. 120.
[34] See Schiebinger, pp. 119-159.
[35] Stefan-Ludwig Hoffman, 'Civility, male friendship and Masonic sociability in nineteenth-century Germany', *Gender and History*, 13 (2) (2001), 224-248 (pp.236-7).
[36] Royal Society, pp. 5-8.

Commons, met with violence and brutality from the Police. In 1912 a campaign of mass window breaking began in the West End, along with post boxes being set alight and the cutting of telephone/telegraph lines. In May 1914, after Mary Richardson slashed the Rokeby Venus, public galleries and museums (including those at South Kensington, frequented by many fellows) were temporarily closed.[37] Hertha joined Mrs Pankhurst's militant WSPU soon after its establishment in 1903. Although she never engaged in violent law-breaking, Hertha did help co-ordinate opposition to the 1912 census boycott and, very publicly, nursed Mrs Pankhurst at her home when the WSPU leader was released and rearrested a number of times during 1913 under the Prisoners' Temporary Discharge Act (the Cat and Mouse Act). As a well-known scientist, Hertha was also asked to lobby scientific men to sign a petition in favour of female suffrage, a task that she did not enjoy. Amongst the notable refusals were Francis Galton FRS and Sir Archibald Geikie FRS, President of the Royal Society.

It is clear that suffrage campaigners challenged what they saw as the male homogeneity of science and that women's access to science became one of a number of pivotal issues around which protest was articulated. By displaying on a protest march a banner reading simply 'Marie Curie, Radium' (figure 7. 1) or 'Caroline Herschel' (figure 7.2) campaigners could convey strong messages about female intellectual equality in an important 'male' sphere.[38] Within the context of this co-ordinated assault on the male privileges of science, Hertha's commitment to the suffrage campaign was enough to cause a mixture of condescension and anxiety in then Royal Society President William Huggins. When Hertha was awarded a Medal in 1906, his letter to Joseph Larmor supposed that there would be 'great joy and rejoicing in H.M.'s gaol, among the women in prison' and that Girton and Newnham Colleges would 'get up a night of orgies on the 30th in honour of the event!'. This may well have been a reference to the highly-publicised celebrations that took place well into the night around a bonfire at Newnham College on the occasion of

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[37] When attending an exhibition at the National Portrait Gallery at around this time, Grace Chisholm Young was amused that she and her lady companion were stopped and searched, presumably for hammers or other items that could inflict damage. LUSA, Young Papers, D140/7/1 (Grace letter, n.d., 1912)

[38] Reference to the Marie Curie banner can be found in Liser Tickner, 'Suffrage Campaigns: The political imagery of the British women's suffrage movement', in *The Edwardian Era*, ed. by Jane Beckett and Deborah Cherry (Oxford: Phaidon, 1987), pp. 100-117; the Caroline Herschel banner is one of a collection held by the Women's Library.

Philippa Fawcett's success at beating the senior wrangler in 1890.[39] But the tone of amusement is absent when he asks 'Can we now refuse the Fellowship to a Medallist?'.[40]

Huggins' image of sexually out-of-control women engaging in 'orgies' was in line with arguments made by opponents of women's suffrage and higher education who pointed to women's emotional motivations and questioned female rationality. Almroth Wright's 1912 letter to *The Times,* referred to earlier, went on to warn about 'militant hysteria' and to argue that women who assert intellectual equality with men are 'plainly' displaying 'an element of mental disorder'. Far from holding 'fringe' views, Sir Edward Almroth Wright was Professor of Experimental Pathology at London University and a respected member of the scientific community; he had been a fellow of the Royal Society since 1906 and had exhibited alongside Hertha at the ladies' conversazione in 1904. His opinions on the shortcomings of the female intellect were shared by other influential fellows. Francis Galton, FRS and member of the anti-suffrage society, had used his statistical research into heredity to 'prove' that women were defective in muscular power and sensory and intellectual activity; his investigation into the abilities of Royal Society fellows and their kinsfolk was published in 1904. Similar views articulated by Central chemist Henry Armstrong, a one time member of the Royal Society council, have been outlined in a previous chapter. Armstrong was vocal in his opposition to the admission of women to the Royal Society, his objections centring on the incapacity of women to be trusted with impassionate, objective scientific method.

Recent scholarship within the history of science has explored the ways in which a piece of work becomes accepted as knowledge. Shapin and Schaffer argue convincingly that this is a social process that depends on the existence of a scientific community that shares a set of social codes and conventions, and within which each (gentleman) member is accorded trust and respect as an equal and a peer.[41] Gender has seldom been addressed within the context of these arguments, yet issues surrounding the access of women to science (and the Royal Society in particular) at the end of the nineteenth century touch directly on concepts of trust and perception of trust. (These issues have been discussed with

[39] Fawcett was carried three times around this bonfire on the shoulders of her fellow students, amid shouts of triumph and celebration.
[40] RSL, Letter 948 (Huggins to Larmor, November 2 1906).
[41] Shapin and Schaffer, pp. 22-79.

reference to women and the laboratory in chapter five.) Darwin had theorised that women's intellect was not on a par with man's and that women were lower down the evolutionary scale, closer to the animals. Women operated on emotion and instinct but men, especially men of science, had the natural gift of rationality. For much of Darwinian-influenced science, women's reasoning was untrustworthy, therefore women's conclusions were questionable and women could never 'by nature' have equal status as scientists, or justifiable ambitions to join an elite scientific society. As the 'hysterical' suffrage campaign gained momentum, with increased militancy, hunger strikes, and the force-feeding of women at Holloway gaol, this view gathered urgency and was used as another layer of evidence to support the anti-woman case.

Hertha and the Royal Society: Discord and difficulty

Although it is difficult to be certain about the motivations of referees, it is possible to point to a growing tendency to question Hertha's scientific reasoning during the first decade of the twentieth century. As early as 1901, a Royal Society referee for her paper on 'The Mechanism of the Electric Arc', which had been so well received by the Institution of Electrical Engineers (IEE), challenged her understanding of key scientific concepts and commented on her 'faulty or at least doubtful reasoning'.[42] Despite this, the paper was accepted for publication in the *Philosophical Transactions*. Her 1904 paper, 'The Origin and Growth of Ripple Mark', was less well received and resulted in a dispute that was to last for the next eleven years. Referees Horace Lamb and John Joly[43] both took issue, advising against publication in the *Transactions* (the outlet for longer papers offering complete research) and offering only reserved support for its appearance in the *Proceedings* (which had originated as a vehicle for abstracts and society news, and which now carried shorter papers and research in-progress). Joly criticised Hertha's proof as 'crude' and accused her of forming 'wide conclusions on apparent slender evidence'. Lamb considered that since 'the dynamics of much simpler phenomena .. is only very improperly understood, an exact theory cannot be expected' and can "only inspire a qualified and

[42] RSL, Referee Report 148 (George Carey Foster, 1901). Carey-Foster (1835-1919) was Principal of University College, London, a position that he had assumed in 1898, previous to which he had been Professor of Experimental Physics.
[43] Sir Horace Lamb (1849-1934) Professor of Mathematics at Manchester University, author of texts on acoustics and fluid dynamics; John Joly (1857-1933) Professor of Geology and Mineralogy, Trinity College, Dublin.

provisional confidence'.[44] Lord Rayleigh and Professors George Darwin and Osborn Reynolds had all failed to explain the phenomena fully, so there was an implication that it was over-ambitious for a woman to have claimed to have done so. These male scientists had position, titles and standing, attributes that were reproduced in the titles of their papers. These 'endorsements' of their veracity and, therefore, the trustworthiness of their work, can be interpreted as a later version of the gentlemanly codes that Shapin and Schaffer identified as crucial to the production of scientific knowledge. Hertha had none of these and her work was not taken on trust. Because of these 'unsatisfactory' theoretical explanations, at the June conversazione her planned oral exposition was replaced by an experimental demonstration. Despite further elaborations read in 1908 and 1911, the Royal Society refused to publish her paper unless she removed the theoretical explanations and deductions. The issue was not fully resolved until 1915 when a paper answering the criticisms, communicated (and therefore endorsed) by Lord Rayleigh, was accepted.[45] Had Hertha's suffrage work prejudiced her position? She certainly thought so, as she expressed in dismay to friend and fellow electrical engineer A.P. Trotter.[46]

Hertha was in her fiftieth year when her 1904 paper was questioned and sixty one when it was finally accepted and published by the Royal Society - an elite body which accepted as fellows only men of experience and standing who had made a marked contribution to science. In this context, maturity was a benefit to men, but for women it could present difficulties. Just as young women, for example the students at the new women's colleges outlined in chapter one, were typically represented as flowers, so older, menopausal women could be described using the metaphors of biological decay, their reproductive organs 'withering on the vine'. Importantly, as a woman's bodily health and mental well being was linked to her reproductive biology, the onset of menopause was not just associated with physical decay but with moral and intellectual degeneracy too. This representation was common in the medical press and advice manuals, both of which exhibited an increasing interest in the menopause in the context of contemporary concerns about motherhood. As late as 1915, one specialist journal asked its male readers to picture their mother-in-law's 'want of sweet reasonableness

[44] RSL, Referee Report 142 (Horace Lamb, 1904) and 143 (John Joly, 1904).
[45] Independent experiments in the 1950s corroborated Hertha's findings, although they made no reference to her work. See Tattersall and McMurran, p. 103.
[46] IEE, Trotter, p. 590.

and her lack of charm' and to consider how her womanliness 'disappears to be replaced by the moustache, the bearing and the assertiveness of the male'.[47] Again, it fell to Almroth Wright FRS to stress that even most women acknowledged that 'half the women in London need to be shut up when they come to the change of life'. He warned readers and doctors never to 'lose sight of the fact that the mind of woman is always threatened with the reverberations of her physiological emergencies'.[48]

Hertha faced numerous difficulties in her later career in addition to the disagreement with the Royal Society over her disputed theoretical conclusions. This latter dispute developed into a long and bad-tempered correspondence. Hertha wrote requesting a copy of the referees' reports, a request which the Society was very reluctant to comply with, fearing controversy. After three more letters from Hertha objecting to this decision, the Royal Society secretary finally gave way and, in a terse note, replied that he would provide her with a copy, 'under pressure' and 'for finality's sake'.[49] Later, Hertha found it almost impossible to fight official apathy and have her design for an anti-gas fan at least appraised. At the outbreak of the WW1, Hertha decided to apply her research on water vortices to the air and designed a fan that could create 'eddies' or vortices of pure air that would drive poison gas away. Trotter describes her experiments in her home laboratory:

> To imitate a gas cloud she used the smoke of brown paper, but this while warm tended to rise above her laboratory battle-field .... (so).... cooling chambers and pipes were devised and made, and smoke poured out and rolled along the floor. A few flaps with a card on a matchbox serving as the parapet of a trench drove it back.[50]

The simple device that ensued, a paddle-shaped fan or 'blade', mounted on a T-shaped handle, which was about a third of a metre

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[47] Marie-Clare Balaam, 'Representations of menopause and menopausal women in turn-of-the-century British medical journals', Women's History Notebooks, 7 (1) (2000), pp. 10-14 (pp. 11-12).

[48] Sir Almroth Wright, 'Militant Hysteria'.

[49] RSL, Letters 91 (April 12 1910); 331 (February 11 1911); 347 (Feb 13 1911); 394 (March 2 1911); 481 (April 5 1911). Letter 331 is from The Royal Society's Asst. Sec., Prof. Harrison, to Prof. J. H. Poynting (Hertha's 'communicator'), asking 'whether you really think it expedient to place it (referee report) in the hands of Mrs Ayrton, and whether it would not be likely to lead only to a controversy instead of to her acceptance of the Committee's decision ..... that the descriptive part only of the paper ..... be recommended for publication, and nothing was said about furnishing her with the grounds on which their decision was arrived at.' Other disputes amongst male protagonists had caused controversy and the Society did not wish to see this repeated. Poynting (1852-1914) was Professor of Physics at Mason College, Birmingham.

[50] IEE, Trotter, p. 585.

square, did not immediately convince the authorities.[51] At the Central Gas Laboratory developments were being made of a far more complex nature, involving large-scale and 'handy' fans with carbon filters and motors, supervised by Royal Society fellows, Professors Watson and Haldane.[52] Again, Hertha's absence from material and social networks of credibility and trust hampered her ideas from receiving consideration, let alone acceptance. This marginalization may have been compounded by the loss of her husband, William Ayrton, who had died six years previously. Ayrton had been a fellow of the Royal Society, an influential figure in the London scientific community and a strong, vocal supporter of Hertha's work, both privately and in public. Hertha could not persuade War Office officials to take her seriously and travel to her home to evaluate these 'toy-like models in her drawing-room'.[53] If her research had been carried out at a prestigious institutional facility, or if she had been able to add the endorsement of 'FRS' after her name, they may have responded with more alacrity and assessed her work without fearing any threat to their own credibility. In the end, a large number of fans were sent to the Front but their efficacy was a subject of dispute, not least in angry exchanges between Hertha and her critics on *The Times* letters page.[54] At least one account of that period implies that she was the tiresome 'wife of a distinguished physicist' (although William Ayrton had died in 1908) whose fan was only accepted after officials caved in, exhausted, to pressure. The writer added that the best use of the fan had been to burn its wooden handle for emergency fuel.[55]

Distinguished men - redundant women: Differing significations of age

Appropriate occupations for older women who were past child-bearing age was a discussion largely absent from the controversies over women's

[51] In a lecture to Girton College in 1920, Hertha described her invention: 'The vortices are produced by flapping one plane on another many times in rapid succession, and it was found that the most efficient fan was constructed by hinging together two flat services - one flexible, of some such material as canvas, and the other rigid, perhaps of wood. The wooden part had to be held firm by a handle or other device, while the rest of the apparatus was flapped on to it by working up and down a stick attached to the canvas'. Ilse F. Stearn, 'A war-time invention: Lecture by Mrs Ayrton, July 27th' *Girton Review*, Jubilee supplement (1920), 42-43.
[52] Kings College, London, The Liddle Hart Centre for Military Archives, The Foulkes Archive, (Records of Central Gas Laboratory).
[53] IEE, Trotter, p. 587.
[54] Hertha Ayrton, 'Anti-gas fans', p. 8.
[55] Major General Charles Howard Foulkes, *'Gas!' The Story of the Special Brigade*, London/Blackwell, 1934, p. 102.

role in the decades around 1900. That very year one contributor to the medical journal *The Lancet*, imagining no useful occupation for women past reproductive age, suggested that they should accept 'voluntary elimination' for the good of the race.[56] Opponents of the suffragettes depicted them as old and ugly spinsters and witches; the image of the 'Dark Widow' was constantly employed, referring in particular to suffragist Mrs Fawcett and militant leader Mrs Pankhurst. This image was also suggestive of Jewishness: dark and 'crone-like', not unlike the sinister image of the 'medical flapper' discussed in chapter three. It could be that Hertha's age, her Jewish background and stereotypical 'dark' hair and looks, together with her public association with suffrage, may have influenced detractors (perhaps unconsciously) against her. Far from claiming a worthwhile role for older women, the suffrage movement's response to such representation was to relocate their leaders back into the accepted norms of femininity and, in their propaganda and imagery, to stress youth. Mrs Fawcett was represented in the literature of the National Union of Women's Suffrage Societies (NUWSS) as above all a wife and mother; the militant WSPU retaliated with ubiquitous images of Joan of Arc - young, beautiful and noble.[57] A reluctance to foreground older women and the difficulty of showing positive representations of them is illustrated by the fictionalised biography of Hertha, *The Call* (1924), written by her step-daughter Edith Ayrton Zangwill. Here episodes from Hertha's life are transposed onto 'Ursula' who is a much younger, beautiful woman.

For the Royal Society there was little nervousness at representing men of a certain age in a positive way: images of mature men of science, in the form of portraits, busts and medals, lined the walls of Burlington House. The election of only older, experienced men, who could be proved to have made a significant contribution to science, was one of the key ways that the Royal Society maintained its difference from other learned bodies. As William Huggins stressed, the admission of young, less experienced men would necessarily take from the Society 'its select and exclusive character, and its distinctive position as an Academy'.[58]

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[56] Balaam, p. 12. This was an extreme view.
[57] Sowan S. Park, *'When Mother joined the suffragettes': The spectacle of women through the gaze of history*, <http://lucy-cav.cam.ac.uk/cwl/OP/Sowon%20Park.htm> [accessed July 4 2002]
[58] Huggins, pp. 38-60 (p. 43).

The Royal Society and younger scientific associations: Maintaining the hierarchy of science

The relationship between the Royal Society and other predominantly younger, specialist societies, was a matter of concern amongst fellows at turn of century. In 1903, Huggins devoted his Presidential Address to the 'grave question' of how long the Royal Society could maintain its 'high position of distinction and influence' without reforming its co-ordination with the specialist societies. The establishment of new learned bodies had been a fast-growing phenomenon in the last quarter of the nineteenth century and between 1860-1900 journals of professional societies in Britain increased from around twelve to seventy.[59] The other broadly-based scientific society was the British Association for the Advancement for Science (BAAS). This had been established in 1831 with the aim of communicating science to the public and building bridges between science and industry. Meetings were held around the country, at industrial and university towns, where series of popular lectures, designed to attract a broad, amateur audience, were delivered. Attendance at meetings did not require a scientific qualification and, after early opposition, women were admitted as members in 1848. However there was controversy well into the twentieth century as to whether women should be eligible to serve as officers and it was not until 1913 that the first woman, botanist Ethel Sargent, was elected as section president.[60] Hertha presented four papers at BAAS meetings in the 1890s and 1900s, although she was never registered as a member. Unlike the Royal Society, BAAS meetings were recognised as social gatherings as well as scientific ones with special 'ladies tickets' available until 1919. One of the ways that the Royal Society marked its elite, scientific superiority over the BAAS was to retain an all-male membership. The Royal Society was not alone in using women (or their absence) as signifiers of status and seriousness. Darwinist Thomas Huxley had prevented women's admission to the Geological Society and engineered their exclusion from the Ethnological Society specifically to

[59] Rose, p. 120.

[60] The position of women in the BAAS remained contentious however. In the early 1920s there was argument over the election of botanist Agnes Arber as a section president with some fellows opining 'that there has been too much indirect influence of women in the botanical world through matrimony for some years, and its does not make for robustness' and 'the Council has been misled by a woman whose myopic vision does not extend beyond the ringfences of Newnham'. Glasgow University, Archive Services, Papers of Frederick Orpen Bower, GB 0248 DC 002/14/18 (letter from Sir Isaac Bayley Balfour to Frederick Orpen Bower, January 20 1921) and GB 0248 DC 002/14/24 (letter from Frederick Orpen Bower to William Abbot Herdman, January 24 1921).

upgrade its professional status in relation to the breakaway anthropologists.[61]

One of the dynamics of the growth of the new societies was the need of amateurs, including women, to find an outlet for their enthusiasm and work when these were refused by older, elite societies. For example, the British Astronomical Association was founded in 1890 to provide an alternative to the Royal Astronomical Society (established 1820) and was advertised as 'open to Ladies as well as Gentlemen'. Several women were active in the Association, participating in expeditions, serving on its council and editing its journal.[62] The Physical Society too, before which Hertha presented two papers,[63] had been established in 1873 partly to provide an outlet for incomplete work which would not have been accepted for publication by the Royal Society. Membership consisted of university and school teachers of physics and amateurs; women had been eligible for membership from the beginning.[64] For many of the newer societies that did not possess a royal charter, the concern was not to exclude members, but to attract them and forge a particular identity. The IEE had been established in 1871 as the London-based Society of Telegraph Engineers. When Hertha lectured before them in 1899 the event attracted welcome attention from the press; IEE members worked at the intersection of commerce and science and were in the vanguard of developing technical applications for public and private use. Publicity that caught the public imagination, of male and, especially, female 'consumers' who may have a say over the use of electrical appliances in the home, was useful to their image and to their business. After speaking before the IEE, Hertha gave a lecture on the electric arc at the populist Electrical Exhibition at Olympia.

Hertha was elected a member of the IEE at the same time as her lecture but her admission papers show that she was admitted under an exceptional clause and did not follow the same election process as the average male fellow. This special clause did not require any electrical education or employment qualification, merely that the candidate 'shall

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[61] Evelleen Richards, 'Redrawing the boundaries: Darwinian science and Victorian women intellectuals', in *Victorian science in context*, ed. by Bernard Lightman (Chicago: University of Chicago Press, 1997), pp. 119-142 (p. 126).
[62] Marilyn Bailey Ogilvie, 'Obligatory amateurs: Annie Maunder (1868-1947) and British women astronomers at the dawn of professional astronomy', *British Journal for the History of Science*, 33 (1) (2000), 67-84 (p.77).
[63] 'The Uses of a Line-Divider' (1885) and 'Experiments on the Production of Sand Ripples' (1907).
[64] For the founding of the Physical Society of London see Gooday, 'Teaching Telegraphy', pp. 80-85.

be so prominently associated with the objects of the Institution that the Council considers his admission to Membership would conduce to its interests'.[65] It was not until 1919 that the next woman became connected to the IEE when Gertrude Entwisle was elected formally as a graduate member. Entwisle was of a retiring nature, worked away from London (in the North West) and did not interact with the press as Hertha had done before her. As a result, the attendance of this female engineer at IEE gatherings was sometimes unexpected: 'When she attended her first IEE meeting, the lecturer mistook her for a militant suffragette and stopped all proceedings' and after her election 'it took half an hour and the special pleading of the Secretary of the North Western Branch to gain admittance (for Entwisle) to the Manchester Engineers Club to attend an IEE meeting'.[66]

Hertha's nomination to the Royal Society

In the context outlined above, the exclusion or inclusion of women was an important tool in defining a society's identity. When they nominated Hertha in 1902, the 'modernisers' were aware that similar campaigns on behalf of women were being rehearsed at other august institutions. The Linnaean Society and the Royal Astronomical Society, both of which shared premises with the Royal Society at Burlington House, had debated the issue. The latter reiterated its refusal to admit women in 1892 when three women were put forward as candidates. The Linnaean Society finally gave way and opened its doors to women in 1904. The Entomological Society, 'formally so exclusive that ladies who contributed papers were not even admitted to be present when they were read'[67] elected its first woman member in 1904 too. Disputes over the admission of women to learned societies had a habit of breaking out onto the pages of the national press instead of remaining behind closed doors. When the Royal Geographic Society debated the possibility of female fellows in 1892-3 an angry dispute between council members was

[65] IEE, Hertha Ayrton election sheet. Hertha was nominated by Joseph Swan and Sylvanus P. Thompson, seconded by John Perry and others.
[66] IEE, *Gertrude Entwisle*, <http://www.iee.org/TheIEE/Research/Archives/Histories&Biographies/Entwisle.cfm> Entwisle (1892-1961) studied physics at Manchester with Rutherford and then transferred to engineering. In 1915 she joined Vickers Electrical Company; she was a founder member in 1919 of the Women's Engineering Society. Her obituary by 'I.H.H.' in *The Times* described her as 'in 1954 the first woman in Britain to retire from a complete career in industry as a professional engineer': I.H.H., 'Miss Gertrude Entwisle', *The Times*, November 27 1961, Obituaries, p. 18.
[67] 'A lady entomologist', *Nature*, 70 (October 13, 1904), Book Reviews, p. 219.

conducted via the letters page of *The Times*.[68] The Royal Society, in keeping with its attachment to an austere, exclusively-male past, turned Hertha down. But rather than cause controversy and dissent among fellows by a straightforward refusal, it argued that its Charter forbade a certificate of candidature from a married woman to be registered or read. As a married woman, Hertha's status in law was covered by that of her husband, therefore she could not be elected a member. The council had sought a legal opinion and this, after much contradictory argument, had advised against the eligibility of married women. The lawyers were less sure about the position of unmarried women, prevaricated, and left the issue in the hands of the council (who ignored it). To admit unmarried women would have required a change to the statutes, something that had been carried out more than once in an effort to control the nature of the membership and election procedures. If the Royal Society had possessed the will to admit married women it could have applied for a supplemental charter as the Royal Astronomical Society had done in 1915 when it finally accepted women.[69]

To president Huggins and councillors Larmor and Armstrong, all of whose negative views on women were well known, allowing discussion of Hertha's nomination may have been interpreted as too dangerous, threatening dissent amongst fellows and criticism in the press, not least in Norman Lockyer's journal *Nature*. (Huggins and Lockyer, astronomers both, were acknowledged as 'arch rivals' by this time and Hertha's election was intimately connected with personal animosities within the Society.) What's more, the Royal Society may have been forced to 'capitulate' as some members of the council were known sympathisers with women's issues. Naturalist William Bateson was a vocal supporter of degrees for women and had founded a 'school' of genetics at Cambridge University comprising primarily of women from Newnham and Girton Colleges; Michael Foster was supportive of higher education for women and allowed female students to attend lectures in his physiology laboratory at Cambridge; astronomer H.H. Turner was a friend of John Perry's and held similar, pro-women opinions. The nervousness of the council over this issue, and their desire to avoid dissent, is evidenced by the letter, sent to every fellow, explaining that

[68] For example: 'Two Fellows of the Royal Geographical Society, 'The Royal Geographical Society and women', *The Times*, August 6 1892, Letters to the Editor, p. 7 and William Hicks, 'The Royal Geographic Society and women', June 10 1893, Letters to the Editor, p. 12. The Council of the Society at one stage issued a circular disavowing the actions of the Secretary; one battle in a long-running dispute.
[69] Mason, 'Hertha Ayrton and Royal Society', reaches this conclusion.

legal opinion had instructed that Hertha's nomination could not be registered or read. In this way the council ducked responsibility for the issue by implying that their hands were (legally) 'tied'. The refusal of a fellowship directly affected Hertha's scientific research and to a certain extent isolated her from developments in her field. In 1910 she was moved to ask the then president, Sir Archibald Geikie, if she could have the privileges of a fellow in the one respect of receiving unpublished papers, as not having this access, she wrote, had put her at 'a great disadvantage'.[70] No evidence can be found of Geikie's response. However the relation of women to the Royal Society became a festering sore which refused to go away.

Women's complaints go public

On June 16th 1914, on a day coinciding with the Royal Society annual soirée, an anonymous correspondent mounted a long and blistering 'Complaint against the Royal Society, The Handicap of Sex' which was published in full in *The Times*.[71] Much of the argument centred on the fact that on the one night when the Society's doors were opened to the public and women, it was the *wives* of scientists and not *woman scientists* who were granted admittance. It continues to complain that

> Women high up in scientific positions, women with international reputations, women who would themselves bear the magic title of F.R.S. if they could disguise from the world the fact of their sex - such women are shut out from the concourse of their intellectual fellows, shut out from the opportunities of meeting and talking with their scientific colleagues ....

The article makes criticism of almost all of the Royal Society's practices, including admission to conversaziones, biased publication policy and the requirement of distinguished women to find a 'communicator' for their papers. It concludes with a call to 'let the world never forget that every discovery published by a woman represents much more than the same discovery made by a man and is a twofold achievement'. (For full text see figure 7.3) Although this article addresses concerns that Hertha had voiced regularly (and in similar language) and makes mention of Marie Curie as a close friend, the piece was not in fact written by Hertha but by Dr Marie Stopes

[70] RSL, Letter 10010 (Hertha Ayrton to Archibald Geikie, November 26 1910).
[71] 'From a correspondent' (Marie Stopes), 'Women and science: Complaint against the Royal Society, *The Times*, June 16 1914, News, p. 5.

(1880-1958).[72] Stopes, remembered for her pioneering work in women's sexuality and birth control, held a degree in botany (University College, London) and had obtained her DSc in 1905 (University of Munich). She was a supporter of women's suffrage and, like Hertha, had joined the short-lived Women's Freedom League, so it is very probable that they were at least acquainted. At the time Stopes was experiencing difficulty in finding a publisher for *Married Love*, the book which was to become her best-known work.[73]

Hertha and the Hughes Medal

Despite the Royal Society's reluctance to admit women as members or add any trace of femininity to its public image, it did publish women's papers and award women the occasional grant. It awarded Hertha its Hughes Medal in 1906, the first woman to receive a medal in her own right (Marie Curie had been awarded the Davy Medal in 1903, along with her husband Pierre). The award of a prize or medal to a woman could be seen as an exceptional rarity and did not compromise the masculine character of the awarding body in the same way that admitting women as members or fellows would.[74] In fact, such awards could be justified within a discourse of gentlemanly patriarchy and endorsed, rather than challenged, men's control of science. John Perry and William Tilden (again) nominated Hertha for the award; Perry was now a member of the Royal Society council, the body in whose hands the election of medallists rested. He had nominated Hertha the previous year, but she had lost to Augusto Righi who was nominated by Larmor and Huggins. 1906 was only the third year that the Hughes Medal had been awarded; it was the last of a flurry of late nineteenth century bequests which included the Davy Medal (1869), Darwin Medal (1888), Buchanan Medal (1894) and Sylvester Medal (1897). After Professor Hughes's bequest in 1900, the Royal Society decided to accept no more as the process of finding suitable recipients was becoming too arduous.

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[72] Information held at News International Archive and Record Office, London E98 1ES.

[73] Walter Blackie of Blackie and Son publishers rejected her manuscript with particular objections to the passage 'far too often, marriage puts an end to women's intellectual life. Marriage can never reach its full stature until women possess as much intellectual freedom and freedom of opportunity within it as do their partners'. Scottish Physicians, 'Marie Stopes, 1880-1958', < *www.fife.50megs.com/marie-stopes.htm*>[accessed February 16 2005]

[74] There were precedents for exclusively male scientific institutions to award women prizes. Sophie Germain had won the grand prize of the Parisian Académie in 1816 for her work on elasticity; mathematician Sophia Kovalevskaia won the Bordin Prize of the French Academy of Sciences in 1888.

Possibly still smarting from his defeat in 1902, in 1905 Perry argued Hertha's case on the grounds that her experimental work was 'so complex that many very clever scientific men abandoned the investigation'.[75] Perry highlighted Hertha's gender again when he and Tilden nominated her a second time in 1906, this time making a case three times longer than the earlier one and claiming that, due to the quality of her work, 'the exceptional step was taken of electing her a Member of that Institution (IEE) of which she still remains, after seven years, the only woman Member among a body of about 6000'.[76] Again Larmor nominated a candidate to stand against Hertha; Elihu Thomson was director of the Thomson-Houston Electrical Company in America where he had emigrated when he was five years old.[77] He was nominated for his work on the improvement of electric meters, the development of electric welding and metal working machinery, and alternating currents. He was not a strong candidate for the Hughes Medal (which was awarded for original discovery) and, in addition, he had previously been awarded the Rumford Medal. Even Larmor could only manage one paragraph arguing the case for Thomson and the vote went in Hertha's favour.

Conclusion

In *The Call*, Zangwill takes us inside the mind of the president of her fictional scientific society (a Huggins-type figure) as he ponders 'disgruntedly' a recent attempt to alter the charters to admit women ' "... it would discredit the Society, reduce its meetings to frivolous social functions." The introduction of frivolity was the reason always advanced .... against the admission of women to masculine institutions'.[78] For Hertha sex had no bearing on the quality or kind of scientific work an individual pursued, as she made clear in an interview with the Daily News in 1919:

> I do not agree with sex being brought into science at all. The idea of 'woman and science' is entirely irrelevant. Either a woman is a good scientist, or she is not; in any case she should be given opportunities, and her work should be studied from the scientific, not the sex, point of view'.[79]

[75] RSL, Medal Claims, 1905 (John Perry for Hertha Ayrton, p. 267).
[76] Ibid., 1906, (John Perry for Hertha Ayrton, pp. 290-291). Presumably Perry was including student and associate members to arrive at this number for IEE membership.
[77] The conflicting requirements of politics and diplomacy may have been the reason why Larmor's candidate was seconded by John Perry, Hertha's prime nominator.
[78] Zangwill, p. 21.
[79] Sharp, *Hertha Ayrton*, p. 182.

At a time of profound social change when many voices, not least scientific ones, were seeking to define women's nature and role, this 'modern' notion of equality between the sexes was not a strong thread. Hertha was at odds with other scientific women who argued that women approached science differently and used this as a justification for feminine participation. Anthropologist Clémence Royer (like Hertha, a friend of Marie Curie) believed that women found their own, 'feminine' way to scientific truth and that their participation was essential to 'debiase science'.[80] In 1913 H. J. Mozens made a plea, based on women's special way of reasoning, for male/female collaborations in science;[81] earlier mathematician Mary Somerville had expressed similar views, inspiring William Whewell's celebrated comment that 'there is sex in minds'. Within the suffrage movement too there was wide consensus that the vote was needed because women did things differently from men, and that women's complementary qualities were urgently required by the State. Hertha's relationship with the Royal Society was informed by a belief that women and men were no different when it came to scientific experiment and discovery; this was a conclusion that the whole culture of that learned body, which held fast to its masculine past, could not admit.

Despite this, the Royal Society had fewer qualms about accepting women's work for publication, offering them the occasional grant, and even awarding women the rare medal; this the Society could achieve without jeopardising gendered spatial and ideological boundaries. Furthermore, acting as the judge of all scientific work, regardless of the sex of its producer, was important for the Society in maintaining its position as arbiter of excellence and gatekeeper of science, especially at a time when the growth of specialist societies was perceived as a threat to its status. Once it had been accepted, Hertha's paper on the electric arc was 'owned' by the Royal Society and she was required to seek the council's permission for publishing it in her 1903 book. In the interests of maintaining its position as the supreme guardian of science, the Royal Society was forced to recognise women's work; in the interests of assuring its high status in relation to other societies, it ensured that women, including Hertha Ayrton, were kept at the margins - never in the fellowship.

[80] Harvey, p. xi.
[81] Mozens, pp. 386-7.

Figure 7.1 Water colour design for Marie Curie Suffrage banner, Mary Lownds (1907-1922) from a collection held by the Museum of London.

Figure 7.2 Suffrage banner designed and made in 1908 by Mary Lownds, part of a collection at The Women's Library.

Figure 7.3 *The Times*, Tuesday, June 16 1914, p. 5 (3 pages)

WOMEN AND SCIENCE.

COMPLAINT AGAINST THE ROYAL SOCIETY.

THE HANDICAP OF SEX.

(FROM A CORRESPONDENT.)

To-night is the annual *soirée* of the Royal Society—the most brilliant of scientific functions. Once in each year (as on the magic nights in the fairy tales) the monastic atmosphere of the headquarters of the oldest and most illustrious of British scientific institutions is spirited away, and troops of ladies mingle with the hoary-headed scientists. I was just about to use the *cliché* "learned ladies," because when the doors of a learned society are thrown open to the sex against which they are usually shut it seems self-evident that it must be the learned ladies, of whom there are now so many, who form the bulk of the guests. But I did not use the phrase, not only because *clichés* are in execrable taste, but because this particular one would be a distortion of the truth; for, with very few outstanding exceptions, it is not the women who are scientific who are invited. Who are the guests? The *wives* of the men Fellows.

Among these ladies some by chance may be scientists in their own right, but as such they receive no recognition—from the point of view of the organizers of the *soirée* they come as wives.

But any Amelia or Leonora whom chance married to a scientific man is eligible as his "lady." Women high up in scientific positions, women with international reputations, women who would themselves bear the magic title of F.R.S. if they could disguise from the world the fact of their sex—such women are shut out from the concourse of their intellectual fellows, shut out from the opportunities of meeting and talking with their scientific colleagues, unless by chance they know some bachelor Fellow, or one whose wife does not care to show off her diamonds, who will take her *incognita* as his "lady." So it happens that while Amelia and Leonora chatter with the learned who are to them only male creatures, Athene is forced to sit at home, the doors barred between her and the men who would be to her intelligences.

ANY MAN BUT NO WOMAN.

A woman was asked a year or two ago to exhibit at the *soirée* some of her recent discoveries. She was flattered and pleased, and at once said "Yes." The man on the committee who had privately asked her about it then said, "You will be able to send some man with them to look after them—one of your students, perhaps?" "I will come myself," the woman answered, and was told she would not be admitted. She could send any man—her footman if he looked presentable—to exhibit her things, but she, their discoverer, was shut out. And to the Ladies' *Soirée*, to which as a mere female she would have been allowed entrance, she was not invited, either as a guest or an exhibitor.

This is so like Gilbert and Sullivan that it seems barely credible in real life until one remembers that it is done by the Society which refuses to have Madame Curie as a Fellow—because she wears skirts.

With strange inconsistency, though women are shut out from the social side which is so valuable a privilege of fellowship, yet their scientific papers, if of sufficient merit, are published in the *Transactions* of the Royal Society. The day the paper is "read" (which is often a pure formality, a technical *résumé*, over in five minutes) the woman whose discoveries it embodies is allowed to come to the meeting, where she is generally the only one of her sex present.

But when the *Transactions* appear with a man's and a woman's paper side by side, how many of the public realize the unequal obstacles which stood in the way of the woman's and the man's achievement? No woman under any circumstances can ever "communicate" her paper herself, as she is not a Fellow, and it must be communicated by a Fellow, who must, of course, be a man. A woman working in at all an isolated field, shut off from the social intercourse the Society affords male scientists, may very easily be in a position where she is dependent on the good will of one or two, even of a single man who is good natured enough to take the trouble to "father" her paper for her. And, strange though this may appear to the uninitiated, the more distinguished the woman, the more original her work, the greater her difficulties in finding a foster parent for it; and even after it has been formally read, the greater the pressure necessary to get the paper published in proper form. She needs not only the good will of one man to communicate it, she must have the good will, or at least the sense of fairness in other men, the referees. A famous woman's work has been hung up unpublished before now for years—work, curiously enough, which demonstrated the errors in the work of a man Fellow of the Royal Society.

The men who are most likely to befriend a woman's scientific work are men much older than she, in whom there is less sense of rivalry. And when, as happens, the one or two on whom she depends die—where is she? A man after publishing several papers in the *Transactions* can generally count on being ultimately made a Fellow himself so that he can communicate his own papers; a woman of the same standing becomes dependent on an ever-decreasing group, and may ultimately have to turn to a younger generation, perhaps even to one of her own students, for the courtesy of "communicating" her work, before she can even send it in for publication.

Another Handicap to the Woman.

Those women who work in institutions may escape another handicap their sisters suffer from. All Fellows, that is, practically all distinguished men scientists, receive from week to week notices telling them the forthcoming papers for the meetings: but a woman may be the one individual in Great Britain capable of discussing a given subject, and she may be unaware that the paper is being read. When, however, by chance, or the kind offices of a man friend, or by the expenditure of 6d. on *Nature*, a woman learns that a paper she ought to hear is to be read, what must she do? She must write round or see the Fellows she knows and find one who will not only vouch for her at the meeting, but will actually be present himself. It has happened before now that a woman specialist was not present at a meeting because it was inconvenient for any of the few men she knew to go themselves.

And in the face of all this and much more of the kind in other directions, men talk about women's inherent incapacity for scientific research! Do the men not realize that it is by sharpening their wits against their fellows from time to time that they themselves are rendered keen enough to carve a way into the unknown? A few women, a steadily increasing number of women, are, in spite of everything, making contributions to science the importance of which cannot be entirely ignored. But let the world never forget that every discovery published by a woman represents much more than the same discovery made by a man and is a twofold achievement.

Exploring the experiences of mathematician Grace Chisholm Young and electrical engineer and physicist Hertha Ayrton has allowed an understanding of how gender was central to the development of pure mathematics and practical science in the decades around 1900. At this time the role of women, along with Victorian ideas of gendered intellect, were changing and adapting in response to the campaign for suffrage, eugenic thinking and the movement for women's higher education. In this fluid, developing context, differing concepts of femininity (and of masculinity too) were one of the pivotal issues around which the pure and the practical sought to establish their differing identities, legitimacy and moral integrity.

Hertha sought to practise as a professional within a modern and meritocratic science that sought to accommodate commercialism and technology as well as research and discovery. Grace was representative of an older tradition which privileged the notions of gifted intellect and an inherited aristocracy of talent and used these ideas to argue for the superiority of pure, abstract mathematics. Following the genesis of these divisions, chapter one pinpointed the seeds of an antagonism between mathematics and physical mathematics and experimental science at Cambridge University and examined the difficulties, both conceptual and actual, of women training for the mathematics tripos at Girton College. Chapters two and three explored the nature and meaning of mathematics and practical or experimental science, following Grace to 'the shrine of pure thought' in Göttingen and Hertha to Finsbury College and the Central Institution at South Kensington, both recognised as providing a pioneering model of technical education. Chapters four and five examined the difficulties faced by both women in attempting to forge separate, individual identities within their chosen areas, and it was illustrated how gendered concepts of trust affected the nature of their acceptance and their representation within their respective communities. Chapters six and seven sought to broaden these findings and situate them within a wider context.

Despite the different locations of the women, and the opposing material, conceptual and epistemological practices of pure mathematics and science, both Grace and Hertha became caged-in by prescriptions of femininity which limited their opportunities and served to keep existing gender hierarchies in place. In many ways, in the decades around 1900 femininity became representative of a reaction against the mechanisation and industrialisation of modern science and technology. Pure mathematics, too, positioned itself against this materialistic modernism by withdrawing from the world and privileging natural intellect. There were good reasons therefore for femininity and mathematics to exhibit an affinity at this time. Despite this, Grace's experience shows how gendered ideas of genius within mathematics served to exclude women - or cause them to exclude themselves - from its highest reaches. At the same time, practical science and engineering cultivated a virile, active identity centring on its provision of technology and 'manly' service to the world. Within this latter conception there was little room for a 'sedentary' femininity assumed to be more at home (literally and metaphorically) with bookwork and mathematics.

The antagonisms so apparent around 1900 were not new but reflected a long-standing chasm between Cartesian 'mind and body', or the more contemporary 'brain and hand'. These divisions, in England at least, were mapped on to notions of class. It is in keeping with notions of the higher moral worth of 'brain work' that lower middle-class Hertha, with her Jewish watchmaker father, should prefer practical science, and that quintessentially middle-class Grace, with her pretensions to an intellectual elite, should privilege the 'pure'. Although it is not suggested that these categories were rigid or did not overlap, these distinctions did cause tensions and inform debate within the scientific community and within bodies such as the Royal Society. The idea of a *learned* scientific method or 'attitude', (applied to life as well as to science) which was a central assumption of technical education, by necessity entailed a certain aesthetic loss. It is significant that 'abstraction' became the indicator of 'genius'. In Rayleigh's view, for example, 'facility for contrivance, backed by unflinching perseverance' were the characteristics of experimentalists, whereas the mathematical physicist was endowed with 'genius and insight'.[1] This hierarchy is based on the amount of abstract mathematics involved, a continuum in which pure mathematics was at the privileged extreme. In this dualism between the pure and the practical there are also echoes of the later 'two cultures' debate which is

[1] Wilson, 'Experimentalists among the mathematicians', p. 133.

predicated on the division between science and the arts.[2] It is significant that within this distinction, where to place mathematics is always an issue.

Neither Hertha or Grace have been aligned within any 'heroic' narrative along the lines of the 'great men' view of history; instead, the focus has been on the more interesting question of how (and if) they were able to negotiate a place for themselves in their relative fields. Hertha encountered obstacles in being accepted as a working professional alongside her male peers. Grace was accepted more readily within the mathematical research community and, at the start of her career at least, facilitated a place in that community for her husband. Both Grace and Hertha's experiences illustrate the limitations of the 'mentor' model to explain fully the access of women to science in the late nineteenth century. Although undoubtedly useful in some instances - and certainly William Ayrton played this role at times for his wife - this model tends to be restrictive and present women as passive agents. Hertha was never the latter, arguing her case whenever necessary, pushing at doors and creating opportunities for herself. It must be remembered that all non-fellows of the Royal Society, male or female, needed a male mentor in the trivial sense that they required a male fellow to 'communicate' their papers.

There is little doubt that the decades surrounding 1900 were a high point for the participation of women in research mathematics. This conclusion is supported by evidence (presented in chapter six) of the high proportion of women taking part two of the Cambridge mathematics tripos, the relatively high ratio of female fellows of the London Mathematical Society, and by women contributors to journals such as the *Educational Times*. That this participation reached a plateau and was not sustained after World War One is further evidence of the changes in configuration of mathematics that would benefit further research, as would cross-cultural comparisons.

In addition to their work and respective legacies to mathematics and science, Hertha and Grace are both remembered by academia. In 1925, Mrs Charles Hancock (Ottilie Blind) endowed Girton College with a £3000 fellowship for the endowment of science in memory of her friend. Grace is remembered by the University of Wisconsin where her son,

[2] C.P. Snow, *The two cultures, with an introduction by Stefan Collini* (Cambridge: Cambridge, University Press, 1993) This book, originally published in 1964, originated from a 1959 lecture.

Laurence Young, became a professor of mathematics. Here the first incumbent of the Grace Chisholm Young Professorship was Mary Ellen Rudin.[3]

An important goal of this study was to illustrate the way in which women have been side-lined in recent important contributions to the history of mathematics and science and to offer (a little) redress. It has been argued in chapters one and six that including mathematicians from Newnham and Girton in any analysis of Cambridge mathematics is important for various reasons: it questions gendered assumptions, opens up a new perspective on the history of the mathematics tripos, and challenges the examination's constant masculine colouring. On the subject of trust and credibility in science, an exploration of women's experiences sheds more light on the processes by which research does, or does not, become accepted as knowledge (or, as discussed with reference to Hertha in chapter five, whether those findings are even considered eligible for consideration). It is important that scholars, especially those with social constructivist credentials, continue to look more deeply behind the tenaciously-masculine representations of mathematics and science in order to reveal what lies behind. It is hoped that this study (along with others) will contribute in a small way to achieving that aim.

[3] Mary Ellen Rudin (1924 -) received her PhD in 1949 and specialises in set-theoretic topology. <http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Rudin.html > [accessed February 16 2005]

Appendix one

Hertha Ayrton : books and papers:

Books:

The Electric Arc (London: The Electrician Printing and Publishing Company, 1903)

Journals:

(Sarah Marks) 'The Uses of a Line-divider', *Philosophical Magazine*, 5, (19) (1885), 280-285

'The Electric Arc', *The Electrician,* (1895 -1896) (series of articles)

'On the equation connecting the potential difference, current, and length of the electric arc' *Report of the British Association for the Advancement of Science'*, 1895, 634

'On the relations between the electric arc curves and crater ratios with cored positive carbons' *Report of the British Association for the Advancement of Science* (1897) 575-577

'On the drop of potential at the carbons of the electric arc', *Report of the British Association for the Advancement of Science* (1898), 805-807

'The Hissing of the Electric Arc', *Journal of the Proceedings of the Institution of Electrical Engineers,* 28 (1899), 400

'The Reason for the hissing of the Electric Arc', *Nature,* 60 (July 29, 1899), 282 – 286. Continued the following week: 'The Reason ... part II' *Nature* 60 (July 27 1899), 302-305

'L'Intensité lumineuse de l'Arc a Courants Continué' *Rapports Preliminaires du Congrès Internationale d'Electricitie* (1900), 250

'The light emitted by the continuous-current arc', *The Electrician,* 45 (1900)

'On the origin of sand ripples', *Report of the British Association for the Advancement of Science,* (1904), 676

'The Origin and Growth of Ripple-Mark' (abstract), *Proceedings of the Royal Society, Series A*, 505 (1905), 565-566

'The Origin and Growth of Ripple-Mark', *Proceedings of Royal Society of London, Series A*, 84 (1910), 285-310.

'On the Non-Periodic or Residual Motion of Water Moving in Stationary Waves', *Proceedings of the Royal Society of London, Series A*, 80 (1908), 252-260

'The Origin and Growth of Ripple-mark', *Proceedings of the Royal Society of London, Series A*, 84 (1911), 285-310

'Local Differences of Pressure Near an Obstacle in Oscillating Water', *Proceedings of the Royal Society of London, Series A*, 91 (1915), 405-410

'Primary and Residual Vortices in Oscillating Fluids – their Connection with Skin Friction' *Proceedings of the Royal Society of London, Series A*, 113 (1926), 44-47

Appendix two

Grace Chisholm Young : books and papers

Books:

'Algebraisch-gruppentheoretische Untersuchungen zur sphärischen Trigonometrie', PhD diss., University of Göttingen, 1895

Journals:

QJPAM (Quarterly Journal of Pure and Applied Mathematics)
PLMS (Proceedings of the London Mathematical Society)
MM (Messenger of Mathematics)

'On the curve, and its connection with an astronomical problem', *Monthly Notices of the Royal Astronomical Society,* 57 (1897), 379-387

'Sulle varieta razional normal ...... rigonometria sferica', *Accademia Reale delle Scienze di Torino,* 34 (1899)

'On the form of a certain Jordan curve', *QJPAM,* 37 (1905), 87-91

'A note on Derivates and Differential Coefficients', *Acta Mathematica,* 37 (1912), 141-154

'On infinite derivates', *QJPAM,* 47 (1916), 127-175

'On the derivates of a function', *PLMS,* 2 (15) 1916, 360-384

'Sur les nombres dérivés d'une fonction', Comptes rendus hebdomadaires des séances de l'Académie des Sciences, 162 (1916), 380-382

'A note on a theorem of Riemann's', *MM,* 49 (1919), 73-78

'Démonstration du Lemme de Lebesgue sans l'emploi des nombres de Cantor', *Bulletin des Sciences Mathematiques,* 43 (2) (1919), 1-3

'On the partial derivates of a function of many variables', *PLMS,* 20 (2) (1922), 182-188

'On the solution of a pair of simultaneous Diophantine equations connected with the nuptial number of Plato', *PLMS*, 23 (2) (1924), 27-44

'Pythagore, comment a-t-il trouvé son théorème?', *L'Enseignement mathematique* 25 (1) (1926), 248-255

'On functions possessing differentials', *Funda Mathematicae,* 14 (1929), 61-94

Published jointly by William Henry and Grace Chisholm Young:

Books:

The First Book of Geometry (London: Greenstreet/Dent, 1905)

The Theory of Sets of Points (Cambridge: Cambridge University Press, 1906)

Journals:

'Note on Bertini's Transformation of a curve into one possessing only nodes', *Rendiconti dell' Acc. Reale di Torino*, 40 (1907), 3-7

'On derivates and the theorem of the mean', *QJPAM*, 40 (1909), 1-26

'An additional note on derivates and the theorem of the mean', *QJPAM*, 40 (1909), 144-145

'On the determination of a semi-continuous function from a countable set of values', *PLMS*, 8 (1909-10), 330-339

'On the existence of a differential coefficient', *PLMS*, 9 (1909-10), 325-335

'Discontinuous functions continuous with respect to every straight line', *QJPAM*, 41 (1910), 94-112

'On the theorem of Riesz-Fischer', *QJPAM*, 44 (1913), 49-87

'On the reduction of sets of intervals', *PLMS*, 14 (1914-15), 111-130

'On the Internal Structure of a Set of Points in Space of any Number or Dimensions', *PLMS*, 16 (1916), 337-351

'On the inherently crystalline structure of a function of any number of variables', *PLMS*, 17 (1916), 1-16

'Sur la frontière normale d'une région ou d'un ensemble', *Comptes Rendus de l'Académie des Sciences,* 163 (1916), 509-511

'On the Discontinuities of Monotone Functions of Several Variables', *PLMS*, 22 (1924), 124-142

Appendix three

William Henry Young : books and papers (to 1914 only)
(publications with Grace Chisholm Young to be found in appendix two)

Books:

The Fundamental Theorems of the Differential Calculus (Cambridge: Hafner, 1910)

Journals:

Proceedings of the London Mathematical Society (PLMS) Series 1:

'On systems of one-vectors in space of n-dimensions', 29 (1897-98), 478-487

'On the null-spaces of a one-system and its associated complexes', 30 (1898-99), 33-53

'On flat-space coordinates', 30 (1898-99), 54-69

'On the fundamental theorem of differential equations', 34 (1901-02), 234-245

'On the density of linear set points', 34 (1901-02), 285-290

'On closed sets of points defined as the limit of a sequence of sets of points', 34 (1901-02), 274 (communication only)

PLMS Series 2:

'On non-uniform convergence and term-by-term integration of series', 1 (1903-4), 89-102

'On closed sets of points and Cantor's numbers', 1 (1903-4), 230-246.

'On sequences of sets of intervals containing a given set of points', 1 (1903-04), 262 - 266

'On the distribution of the points of uniform convergence of a series of functions', 1 (1903-4), 356-360

'Open sets and the theory of content', 2 (1904-5), 16-51

'On upper and lower integration', 2 (1904-5), 52-66

'The tile theorem', 2 (1904-5), 67-69

'Ordinary inner limiting sets in the plane or higher space', 3 (1905-6), 371-380

Linear content of a plane set of points', 3 (1905-6), 461-477

'On uniform and non-uniform convergence and divergence of a series of continuous functions and the distinction of right and left', 6 (1908), 29-51

'On the uniform approach of a continuous function to its limit', 6 (1908), 210-223

'On the inequalities connecting the double and repeated upper and lower integrals of a function of two variables', 6 (1908), 240-254

'Oscillating successes of continuous functions', 6 (1908), 298-320

'On differentials', 7 (1908-9), 157-180

'On implicit functions and their differentials', 7 (1908-9), 397-421

'On indeterminate forms', 8 (1909-10), 40-76

'On term-by-term integration of oscillating forces', 8 (1909-10), 99-117

'On the discontinuities of a function of one or more real variables', 8 (1909-10), 117-124

'On homogeneous oscillation of successes of functions', 8 (1909-10), 353-364

'On a new method in the theory of integration', 9 (1909-10), 15-50

'On semi-integrals and oscillating successes of functions', 9 (1909-10), 286-324

'A note on the property of being a differential coefficient', 9 (1909-10), 360-368

On the conditions that a trigonmetrical series should have the Fourier form', 9 (1909-10), 421-433

'On the integration of Fourier series', 9 (1909-10), 449-462

'On the theory of the application of expansion to definite integrals', 9 (1909-10), 463-485

'On the fundamental theorem in the theory of functions of a complex variable', 10 (1912), 1-6

'On the convergence of a Fourier series and of its allied series', 10 (1912), 254-272

'On the nature of the successions formed by the coefficients of a Fourier Series', 10 (1912), 344-352

'On successions of integrals and Fourier series', 11 (1913), 43-95

'On multiple Fourier Series', 11 (1913), 133-184

'On a certain series of Fourier', 11 (1913), 357-366

'On the Fourier Series of bounded functions', 12 (1913), 41-70

'On the determination of the summability of a function by means of its Fourier constants', 12 (1913), 72-88

'On derivates and their primitive functions', 12 (1913), 207-217

'On functions and their associate sets of points', 12 (1913), 260-287

'On uniform oscillation of the first and second kind', 12 (1913), 340-364

'On the mode of oscillation of a Fourier series and its allied series', 12 (1913), 433-452

'On the usual convergence of a class of trigonometrical series', 13 (1913-14), 13-28

'On integration with respect to a function of bounded variation', 13 (1913-14), 109-150

Quarterly Journal of Pure and Applied Mathematics (QJPAM):

'On the analysis of linear sets of points', 35 (1904), 102-115

'Note on the condition of integrability of a function of a real variable', 35 (1904), 189-192

'The potencies of closed and perfect sets', 36 (1905), 280-283

'On regions and sets of regions', 37 (1906), 1-35

'On the distinction of right and left at points of discontinuity', 39 (1908), 67-83

'On the construction of a pointwise discontinuous function all of whose continuities are infinites and which has a generalised integral', 39 (1908), 217-221

'Note on left and right-handed semi-continuous functions', 39 (1908), 263-265

'Note on a remainder of Taylor's theorem', 40 (1909), 146-152

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