MARY SOMERVILLE: BEING AND BECOMING A MATHEMATICIAN

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ABSTRACT

Mary Somerville (1780–1872) was unequivocally one of the best-known mathematicians in Britain during the first half of the nineteenth-century. Barred from receiving a formal education, she tenaciously pursued her studies through independent reading and the solving of problems published in the Question and Answer sections of journals. Through her deft navigation of polite society in Edinburgh, London, and Paris, she was able to build a reputation for herself as an expert in analytical mathematics, especially as practiced and taught in France. At a time when British mathematics was widely perceived to be in decline, Somerville positioned herself within a network of mathematicians who saw the adoption of analytical methods as the way to reform. Moreover, she was able to leverage her knowledge of this esoteric and highly valued mathematics to build a successful career as an author of scientific books which lasted over forty years. However, the type of books that Somerville wrote and published, especially as regarding mathematical content, was heavily influenced by her desire and need to make a profit from her writing. This thesis presents the first scholarly treatment of Somerville's path as a mathematician, broadly conceived to include her engagement with scientific society alongside her written works, and provides new insight into the circulation of French analysis in early-nineteenth-century Britain.

Let us have all you can possibly remember of past times,
for there were giants in those days & you did good battle yourself
against the nothingness of women's lives & thoughts & works
— though you were too polite ever to tell them,
how you were undermining their Paper castles & erecting
another standard of admiration and love

— Margaret Brodie Herschel to Mary Somerville
MS Dep. c. 370, MSH 3 306, 5th January 1869

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My research on Mary Somerville began as an undergraduate in Oxford, and I am indebted to Christopher Hollings for his encouragement and mentorship during the writing of my undergraduate dissertation, without which I would never have pursued a research degree. At this time I was incredibly lucky to become involved with the Oxford Forum for the History of Mathematics, and the British Society for the History of Mathematics. During my doctoral studies I

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MARY SOMERVILLE, A MATHEMATICIAN?

As a scientific woman of great renown in the nineteenth century, it has long been appreciated that Mary Somerville's entry into and place within the intellectual milieu of the time was somewhat unusual. Despite having little access to formal education, especially in mathematics and the physical sciences, Somerville was nevertheless able to cultivate a reputation for herself as an expert in these areas. Perhaps more important than being celebrated by members of the scientific community throughout Europe and North America — which she was —, Somerville collaborated with her contemporaries as an equal, in the common endeavour to expand the limits of human knowledge.

Somerville has variously been celebrated as a mathematician, philosopher, astronomer, or, rather anachronistically, a scientist.[1] When reflecting back on her own life at ninety years of age, it was mathematics that she saw as her greatest passion, and her highly algebraic *Mechanism of the Heavens* as her greatest achievement. She believed that all her other books would soon be forgotten, and that by *Mechanism* alone would she be remembered (Patterson, 1983, p. 89). This thesis gives the first comprehensive look at how Somerville became a mathematician, and what it meant for her to inhabit that title.

1.1   THE QUEEN OF NINETEENTH-CENTURY SCIENCE

Mary Somerville, one of the "most distinguished astronomers and philosophers" of the nineteenth-century, was born Mary Fairfax in 1780 (Secord, 2004, Volume 1, II.29, Pg 1). She was the daughter of Navy Lieutenant William George Fairfax and his wife Margaret Charters Fairfax, both of whom were distantly related to noble and ancient Scottish houses, although neither had private wealth of their own.

Somerville, the name by which she is known and hence the name by which she will be referred to throughout this thesis, grew up in a small seaside town called Burntisland, just outside of Edinburgh, in

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1 Indeed Somerville is often named 'the world's first scientist' because the Oxford English Dictionary gives the first use of the word as William Whewell's review of her *On the Connexion of the Physical Sciences* in 1834. However, he did not use the word scientist to describe Somerville and nor seemingly did anyone else. In fact, the word did not come into common usage in Britain until the 20th century (Secord, 2018).

Figure 1: Self Portrait, Mary Somerville. Undated.

(a) Front door and plaque.   (b) Somerville's childhood home.

Figure 2: Somerville's childhood home in Burntisland, with a plaque recognising her achievements. The area on which the house stands is now called Somerville Square. Photographs the author's own, taken June, 2018.

Fifeshire, Scotland. Most of the information we have about her childhood comes from the autobiographical *Personal Recollections, from Early Life to Old Age, of Mary Somerville* published posthumously in 1873; written in the late 1860s, when Somerville was nearing ninety years old. With hindsight she was able to identify many ways in which she had been informally exposed to the wonders of science and nature in her youth, such as the practice of preserving boiled fruit by burying it underground, and the beautiful impressions of leaves she observed on blocks of limestone by the pier, which she would only later discover were fossils (Somerville and Somerville, 1873, pp. 18, 25, 94).

As a member of the middle-classes, or gentry, once she came of age Somerville spent much time in Edinburgh society, at that time "a gay, sociable place" where "most of the Scotch families of distinction spent the winter" (Somerville and Somerville, 1873, pp. 61–62). As a young girl she had spent time at her uncle's house in Edinburgh where she attended 'Strange's dancing school', learning to curtsy as well as to dance minuets, reels, and country dances (Somerville and Somerville, 1873, p. 42). Whilst her brother was sent to the high school and university in Edinburgh for an education, Somerville was brought up to be an 'accomplished' young lady, playing the piano, reading Ancient Greek and Latin, learning needlework, and taking painting

(a) Edinburgh House.

(b) Plaque at the door.
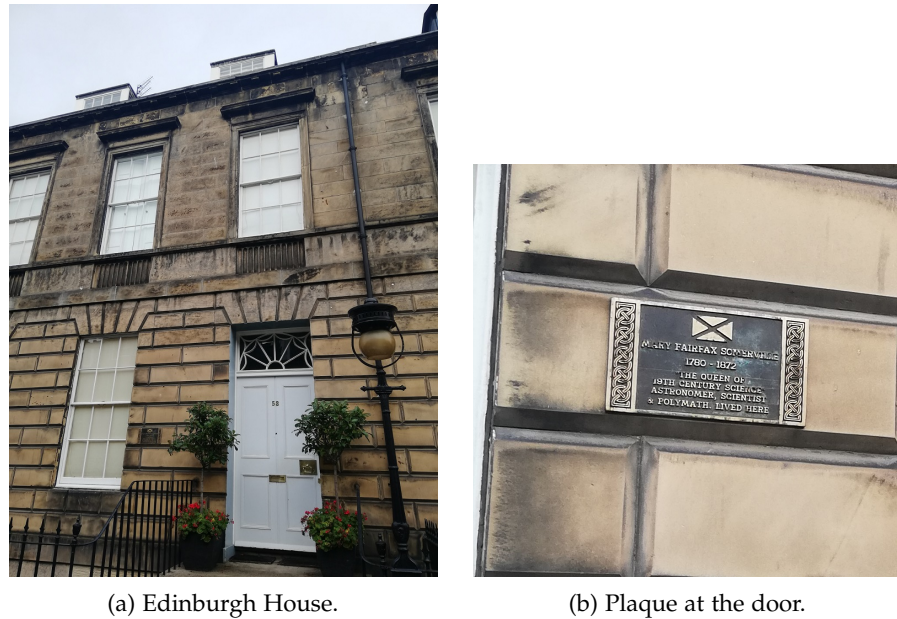
Figure 3: The house on Northumberland Street, Edinburgh where Somerville lived; the plaque reads "Mary Fairfax Somerville. 1780–1872. The Queen of 19th Century Science, Astronomer, Scientist & Polymath. Lived Here". The premises of the Royal Society of Edinburgh on George Street would have been a ten minute walk away. Photographs the author's own, taken June, 2018.

lessons from Alexander Nasmyth.[2] That Somerville possessed the demeanour and talents to move easily through polite society is clear from her supposed nickname "The Rose of Jedwood" (referencing her birthplace of Jeburgh in the Scottish Borders), and her stories of frequently attending concerts, balls, and the theatre in Edinburgh.[3] Somerville maintained her varied interests throughout her life, with

2 Alexander Nasmyth (1758–1840) was a distinguished Scottish portrait and landscape painter.

3 We here use 'polite' to indicate the social prestige of the communities with which Somerville was engaging, usually the landed gentry or equivalent. See (Vickery, 1999, p. 13). Somerville's list of acquirements is reminiscent of Jane Austen's pointed description of an accomplished lady in her her 1813 novel *Pride and Prejudice*, which was first drafted in 1796. Character Caroline Bingley claimed that "a woman must have a thorough knowledge of music, singing, drawing, dancing, and the modern languages, to deserve the word [accomplished]; and besides all this, she must possess a certain something in her air and manner of walking, the tone of her voice, her address and expressions, or the word will be but half-deserved." Fitzwilliam Darcy felt that "to all this she must yet add something more substantial, in the improvement of her mind by extensive reading", to which protagonist Elizabeth Bennet retorted "I am no longer surprised at your knowing only six accomplished women. I rather wonder now at your knowing any!" (Austen, 1813). Somerville herself thought Austen's novels 'excellent', especially *Pride and Prejudice* (Somerville and Somerville, 1873, p. 144).

Figure 4: An Extensive Landscape of River Valley and Distant Mountains,
by Mary Somerville. Somerville College, Oxford

some of her landscapes of Scotland and Italy now hanging in Somerville College, Oxford. The social acquaintances she cultivated through her adept navigation of polite society were vital to her engagement with a scientific community during her lifetime.

However, during her childhood, she seems to have been strongly discouraged from her intellectual pursuits. In her *Recollections* she talked of feeling silenced by her aunt and uncle on the subjects that most interested her when staying with them in Edinburgh, and frustration that her enjoyment of reading invited disapproval, as she felt it "unjust that women should have been given a desire for knowledge if it were wrong to acquire it"(Somerville and Somerville, 1873, pp. 28, 42).

The earliest evidence that remains of Somerville actively engaging in a scientific community is from after she had the social and financial freedom of a widow. In 1804, Somerville had married a second cousin, Samuel Greig, with whom she moved to London. Her descriptions of this time were predominantly negative; she felt isolated from society and was left alone for most of the day in Greig's small and ill-ventilated 'bachelor's house' (Somerville and Somerville, 1873, p. 75). In 1807 Greig died, and Somerville returned to Burntisland with two young sons, the younger of whom sadly passed away in childhood. Somerville continued her mathematical studies, and in

1811 was awarded a silver medal engraved with her name for a solution to a mathematical puzzle she submitted to the periodical *The New Series of the Mathematical Repository* (see Chapter 2).

In 1812 Somerville remarried, this time to her first cousin William Somerville (and so assumed the name by which she became publicly known). She returned to London in 1816, but this time was anything but isolated; William actively supported her intellectual pursuits and she was frequently out in society becoming acquainted with many of the most influential men and women of science at the time. Moreover, the Somervilles travelled throughout Europe, building an expansive network of scientific acquaintances (see Chapter 3).

Somerville's first publication under her own name was a paper in *The Philosophical Transactions* of the Royal Society of London in 1826, detailing an experiment she had carried out on the magnetising properties of light. This paper was very well received, and appeared in translation in French and German that same year.[4] In 1831 Somerville's first book, *Mechanism of the Heavens*, was published, an edited version of Pierre-Simon Laplace's *Mécanique Céleste* which treated the motions and shapes of the bodies in the solar system. For this first book Somerville wrote a 70-page *Preliminary Dissertation* which she expanded into a book-length survey of recent developments in the physical sciences and published as *On the Connexion of the Physical Sciences* in 1834. *Connexion* went through three more editions during the 1830s, with each new edition undergoing substantial revisions and edits to ensure that the content kept pace with emerging research.[5] Alongside her writing, Somerville continued to conduct experiments to investigate the properties of visible light, and whilst she did not necessarily write up her results with the intention of publication, as was common at the time extracts of her letters were published in the journals of learned societies which brought her results to the attention of the scientific community.

Although Somerville had certainly been well-known as a mathematician since at least 1817, it was during the 1830s that she began to receive accolades for her scientific work. This included honorary memberships of learned societies, the awarding of a pension from the British government, and the commissioning of a bust by renowned sculptor Francis Chantrey to be placed in the meeting room of the Royal Society of London.

Owing to the ill health of William Somerville and the prospect of lower living costs, in 1838 the Somervilles and their two daugh-

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4 The results of this experiment were later contested, see section 3.3.
5 For a complete list of Somerville's published works, see figure 1.

ters left London behind for Rome. They would never again return to live in London, instead moving between cities throughout the Italian peninsula, without a permanent address. This period of her life has been described by Patterson as "outside of the mainstream of science", but as is clear from Somerville's list of publications she continued to publish new works until the end of her life. In fact, her third book *Physical Geography*, first published in 1848, was awarded the Victoria Medal from the Royal Geographical Society (based in Britain) and the Gold Medal of the Geographical Society of Florence; its reach spread as far as India where it was adopted as a 'book of instruction' at multiple colleges (Anon, 1872c, p. 6). Furthermore Somerville continued to be elected to honorary memberships of learned societies throughout Europe, even to two societies based in the United States of America.[6] Her final book, *On Microscopic and Molecular Science* was published in 1869.

On her death in 1872, obituaries were published in newspapers throughout Europe and North America. In her country of birth announcements of her death were published in local newspapers from Essex to Aberdeen, Newcastle to Bangor. In reference to Mary Somerville, the *Morning Post* claimed that 'whatever difficulty we might have in the middle of the nineteenth century choosing a king of science, there could be no question whatsoever as to the queen of science' (Anon, 1872a). Multiple newspapers announced her death as a loss of one of the greatest ornaments of the literary and scientific world, and the *Belfast Newsletter* named her "the principal representative of science who has died in the [preceding] year" (Anon, 1872b). Most of the announcements recognised Somerville for her published works, especially *Connexion*, with others relying on the approbation of her scientific contemporaries to outline her intellectual attainments. Somerville was recognised as a central figure in nineteenth century science, alongside John Herschel, David Brewster, and Alexander von Humboldt, both during and immediately after her lifetime. She was not merely the most well known 'woman of science', or notable as one of few women who excelled in scientific pursuits, but was celebrated alongside her male contemporaries for her role in the collective endeavour to expand the bounds of human knowledge.

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6 MS Dep. c. 375.

Table 1: Publications of Mary Somerville

Year	Publication
1814–1819	Solutions to mathematical puzzles in the *New Series of the Mathematical Repository*, see Appendix A [Anon]
1826	'On the Magnetizing Power of the More Refrangible Solar Rays', *Philosophical Transactions of the Royal Society of London* 'Sur le pouvoir magnétique des rayons les plus réfrangibles du soleil, par M.ress Somerville, traduit par A. Quetelet', *Correspondance Mathématique et Physique*, Volume 2 'Ueber die magnetisirende Kraft der brechbareren Strahlen des Sonnenlichtes von Mistress Mary Somerville', *Annalen der Physik*, Volume 82
1831	*Mechanism of the Heavens*
1834	*On the Connexion of the Physical Sciences*
1835	'1.*Ueber den Halleyschen Cometen* Von Littrow, Wien. 1835. 2.*Ueber den Halleyschen Cometen*. Von Professor von Encke. Berliner Jarbuch. 1835. &c. &c. &c.' *Quarterly Review*, Volume 55 [Anon] *On the Connexion of the Physical Sciences*, 2nd Edition
1836	'Expériences sur la transmission des rayons chimiques du spectre solaire, à travers différents milieux. Extrait d'une lettre de Mme Sommerville à M. Arago', *Comptes rendus hebdomadaires des séances de l'Académie des Sciences*, Volume 3 *On the Connexion of the Physical Sciences*, 3rd Edition
1837	'Extract of a letter from Mrs Somerville to M. Arago, Detailing some Experiments Concerning the Transmission of the Chemical Rays of the Solar Spectrum through Different Media', *Edinburgh New Philosophical Journal*, Volume 22 *On the Connexion of the Physical Sciences*, 4th Edition
1840	*On the Connexion of the Physical Sciences*, 5th Edition
1842	*On the Connexion of the Physical Sciences*, 6th Edition
1846	'On the Action of the Rays of the Spectrum on Vegetable Juices. Extract of a letter from Mrs. M. Somerville to Sir J. F. W. Herschel, Bart., F.R.S. dated Rome, September 20, 1845', *Philosophical Transactions of the Royal Society of London*, Volume 136

1846	*On the Connexion of the Physical Sciences*, 7th Edition
1848	*Physical Geography*
1849	*On the Connexion of the Physical Sciences*, 8th Edition
	Physical Geography 2nd Edition
1851	*Physical Geography* 3rd Edition
1858	*On the Connexion of the Physical Sciences*, 9th Edition
	Physical Geography 4th Edition
1862	*Physical Geography* 5th Edition
1869	*On Microscopic and Molecular Science*
1870	*Physical Geography* 6th Edition

1.2 REMEMBERING MARY SOMERVILLE

Somerville continued to be remembered after her death through her own *Personal Recollections*, which was well received on its first publication in 1873.[7] Having assembled a substantial collection of letters, notebooks and manuscripts during her life to which she could refer, Somerville was able to give a detailed account of her life at the centre of polite scientific society throughout much of the nineteenth century. Notably we get a first-hand account of the life of a woman who chose to pursue her mathematical and scientific interests at a time when the contributions of women were, or have since been rendered, invisible.

Somerville was also frequently featured in the published collections of letters and papers of her contemporaries, where she appeared in journal entries or as a correspondent: she appeared numerous times in the journal of geologist Charles Lyell who spoke of chaperoning her at parties and of her forthcoming publications (Lyell, 1881); she of course appeared in the correspondence of her publisher John Murray (Smiles, 1891); and American astronomer Maria Mitchell's *Life, Letters and Journal* included Mitchell's struggle to acquire a letter of introduction to Somerville, which she eventually sourced from the Herschels, enabling her to pay a visit to Somerville in Florence (Kendall, 1896, pp. 159–162).[8] From the middle of the nineteenth cen-

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7 The *Personal Recollections* then fell out of print until the American Mathematical Society reprinted the American edition in 1975, and in 2001 Canongate published a version edited and introduced by Dorothy McMillan (McMillan, 2001). A digitised version can now be read at archive.org.

8 Somerville also features in the following edited collections of letters and papers of her contemporaries: (Warner, 1855); (Farrar, 1866); (Herschel, 1876); (Todhunter, 1876); (Douglas, 1881); (Graves, 1882); (Clark and Hughes, 1890); (Bowditch, 1902).

tury potted biographies of Somerville appeared in anthologies of notable women, such as Sarah Josepha Hale's 1853 *Woman's Record*, which were written to celebrate the achievements of women and often to argue for or against the widening of access to education or the expansion of suffrage to women (Hale, 1853), (Fawcett, 1889).[9]

During the 20th century Somerville's place in the history of science became marginalised and forgotten, as the dominant narrative of scientific progress was built up around landmark moments, or grand theories and 'original discoveries' of individuals. Somerville had no theorem to which she could give her name, no novel experimental technique nor conjectured general law of nature, and so did not easily find a place in such histories (Neeley, 2001, p. 218).[10] However, in 1879, a higher education college for women had been founded in Oxford and named Somerville Hall — now Somerville College — in honour of Mary Somerville. The founders specifically wished to name the hall after a woman who was known for her intellectual pursuits and liberal politics, in contrast to Lady Margaret Hall which was founded concurrently and named after a pious benefactor of the University (Adams, 1996, p. 13). Not only did the college maintain the presence of the name Somerville in the public domain, but it has also since its founding assembled an extensive archive of Somerville's papers, letters, paintings, and recently even her shell cabinet complete with shell samples.[11] These resources, along with letters held in archives of learned societies and libraries provide detailed information on her personal and scientific life, and are a fruitful resource for studies of nineteenth-century science more broadly.[12]

By far the most comprehensive biography of Mary Somerville is that of Elizabeth Chambers Patterson (Patterson, 1983). In the late 1960s and early 1970s, Patterson catalogued the Somerville papers

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9 One such argument against education for women is that Somerville was able to contribute to the advancement of science without forgoing her femininity, and that by agitating for a university education women risked "losing the true substance of female education by endeavouring to grasp at some shadowy substitute" (Anon, 1872d). For a more comprehensive study of how examples of scientific women were used in discussions on women's place in science and society in the second half of the nineteenth century see Boucard on Sophie Germain, (Boucard, 2020).

10 In fact, Somerville already caused historiographical dilemmas in the 1830s. William Whewell was criticized for not mentioning her in his 1837 *History of the Inductive Sciences*, to which he retorted that "there was no pretext for mentioning her in a history of original discovery" (Todhunter, 1876, 260, Vol 2), (Whewell, 1837).

11 A significant portion of these archival materials were deposited by the Fairfax-Lucy family, descendents of Somerville's brother.

12 Metadata and transcripts of many letters by or to Somerville can be found in ɛpsilon, a digital collection of 19th-century scientific correspondence, located at epsilon.ac.uk.

which are held at the Bodleian Library, University of Oxford, on behalf of Somerville College. This intimate knowledge of the archival material is clear throughout the biography, which focuses predominantly on Somerville's life in London between 1816 and 1838. Patterson identifies this time as Somerville's most scientifically productive, and demonstrates clearly her central place in the networks of scientific and literary persons of the nineteenth century.

More recently, there has been a proliferation of studies on Mary Somerville, including multiple books and articles. Building on the extensive scholarship on women in science that has been produced since the 1960s, (Neeley, 2001) investigates the gendered aspects of Somerville's participation in science, from how she accessed education to the choices she made to resist or acquiesce to expectations of 19th-century womanhood when building her career.[13] Through a consideration of manuscript drafts of *Personal Recollections*, Neeley demonstrates that during the writing and editing process this autobiography was curated to promote a memory of Mary Somerville as a good and virtuous woman. Significant editing was done by Somerville's eldest daughter Martha Charters Somerville, as well as her close friend Frances Power Cobbe, removing such passages as:

> my uncle Thomas Charters, an officer in the Indian Army then on leave, amused himself by teaching me to swear. One day walking with my maid in the High Street a lady asked me my name and I answered, 'What's your business you damned B–'. (McMillan, 2001, p. 9).[14]

Extracts from many letters written to, by, or about Somerville were also introduced into the narrative to support their positioning of Somerville as a respected but feminine scientist. Neeley further outlines the difficulties for historians of science in writing about Somerville as she defies the usual categories by which women are included in the historical narrative, for example as helper, translator, or writer 'for the ladies' (Neeley, 2001, pp. 30, 196); that this difficulty of categorising Somerville's role as a public figure and an educator existed even during her lifetime was subsequently demonstrated in (Brock,

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13 Using career in the sense of "a person's course or progress through life (or a distinct portion of life), especially when publicly conspicuous" (Oxford English Dictionary definition) rather than to suggest Somerville earned a salary by her scientific work.

14 The manuscript drafts of *Personal Recollections* are held in MS Dep. c. 355, MSAU–2. (McMillan, 2001) re-introduced a significant number of extracts from the manuscripts that were removed during the editing process. For an investigation of self-representations of women in science beyond Somerville, see (Kohlstedt and Opitz, 2002).

2006).[15] Finally, Neeley treats the poetic and literary influences that are evidenced in Somerville's work, and the rhetoric devices she used to convey scientific information. The symbiotic relationship between science and literature in nineteenth-century Britain, and in the work of Somerville specifically, has been further treated in (Jenkins, 2007), (Speese, 2013), (Wiegand Brothers, 2015), and (Boswell, 2017).

Somerville's ouvre was used by Robyn Arianrhod, in conjunction with the work of Emilié du Châtelet (1706–1749), as a window into the scientific and mathematical developments made in the eighteenth and nineteenth centuries (Arianrhod, 2012). The contingency of these developments on the political and social climate of the early nineteenth century was investigated by James Secord in (Secord, 2014).[16] Here, he presents Somerville's first two books alongside the works of John Herschel, Charles Lyell, and Humphry Davy, as exemplars of the reflective scientific literature which emerged in a unique moment of change in 1830s Britain, heavily influenced by ongoing political reform, the expansion of the British Empire through trade and military conquest, and the spread of reading throughout the middle and upper working classes. Somerville's first book, *Mechanism of the Heavens*, was in fact originally to be published by the Society for the Diffusion of Useful Knowledge (SDUK), which aimed for "nothing less than the complete reformation of society" through self-education and reading (Secord, 2014, p. 14). Somerville's books actively advocated for mathematical literacy as a way to understand "the divine transcendence of God's power", as a riposte to the sentiment that the higher mathematics developed by the French, which was invaluable in studies of the physical sciences, would inevitably lead to atheism or materialism.

As the daughter of a naval officer, wife of a diplomat and then of an Army physician, and with a brother in the service of the East India Company, Somerville's life was constantly influenced by Empire. Ideology of Empire, progress and civilization certainly made their way into her scientific books, where she explicitly discussed her perceived hierarchy of human beings, and her belief that civilization would inevitably lead to the extinction of 'lesser races' (Secord, 2004, Vol 1, xxxiii). In her *Mechanism of the Heavens*, the stability of the solar

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15 (Lightman, 2009, pp. 21–22) situates Somerville within Victorian 'popularizers' of science more broadly.

16 Secord had previously edited Somerville's collected works, the first volume of which is a valuable resource containing an introduction by Secord, numerous contemporary reviews of Somerville's works, obituaries, and facsimiles of Somerville's shorter published works (Secord, 2004). Digitised copies of all of Somerville's books can now easily be found on eg. archive.org, although without the informative introductions written by Secord.

system was entwined with natural theology to demonstrate the inevitability of progress, which itself relied on a global commerce and circulation of knowledge (Meyer, 2010, p. 142). Somerville's participation in Empire was by no means passive; she lent her name to a ship which — with special permission — bore a copy of her bust as its masthead, and which carried goods between Liverpool, Kolkata (Calcutta) and Guangzhou (Canton) for almost twenty years (Secord, 2004, Vol 1, page xxxvii). Moreover Somerville prepared supplies of orange marmalade for arctic explorer Edward Parry before a voyage looking for minerals, and in return he named a small island in the Barrow Strait of Northern Canada after her (Fara, 2008, p. 84).[17]

That Somerville was able to rise to the forefront of scientific endeavour through self-directed reading and social connections was predominantly owing to the informal culture of science in nineteenth-century Britain. Allan Chapman characterises the community as one of 'Grand Amateurs': grand both for the affluency of the members and for their aspiration to do original work that would expand the bounds of scientific knowledge; amateur as this was done as an avocation rather than for monetary motivations (Chapman, 2015, p. 2). Chapman underlined the ubiquity of knowledge exchange in social settings, such as private dinners where the entertainment consisted of taking observations at the privately owned observatories of astronomers like James South and William Henry Smyth, and the importance of these activities to Somerville and to grand amateurs in general (Chapman, 2015, pp. 33–34). The openness of this community, which valued breadth of knowledge above extreme specialisation, is reflected in the variety of disciplines to which Somerville contributed, including astronomy (Brück, 2009); chemistry (Parkin, 2001); geography (Baker, 1948), (Sanderson, 1974); and geology (Larsen, 2017).

Access to scientific knowledge and to spaces of knowledge production attained by women throughout history continues to be a fruitful area of research, and one in which Somerville frequently features. As well as uncovering the work of women that was not previously known or recognised, scholars have also consciously widened the scope of what is understood as a contribution to scientific progress, and re-evaluated the significance attributed to women's work as writers, transcribers, assistants or travelling companions (Schiebinger, 1991), (Fara, 2004). These re-evaluations are necessarily informed by studies of contemporary ideas of women's intelligence, and the authority they were thus granted (or not) to speak on topics such as nature or

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17 There is also a crater on the moon named for Mary Somerville (Altschuler and Ballesteros, 2019).

mathematics (Gates, 1998), (Jones, 2009). As women's contributions so often took place in the so-called 'domestic sphere', this train of research has led to an investigation of the role of domesticity in the production of knowledge more broadly, unrestrained by the gender of the practitioners (Opitz, Bergwik, and Van Tiggelen, 2016).

Public interest in women in science, technology, engineering, and mathematics (STEM) has boomed in recent years, in response to demand for better representation of women in scientific careers. As part of this trend, Somerville has catapulted back into the public eye. In 2016, after a (mildly) heated competition, the British public chose Mary Somerville to feature on the new Royal Bank of Scotland £10 note, which was subsequently released into circulation in October 2017.[18] This created a renewed interest in Somerville and her work, with articles appearing in *New Scientist* and *Physics Today* (Baraniuk, 2017), (Secord, 2018). She was subsequently spotlighted as the focus of a 'Google Doodle', the imagery on the Google homepage, which celebrated her as a "groundbreaking Scottish scientist".[19] Somerville is featured in numerous online articles celebrating notable scientists and their achievements — for example, her 1826 paper was spotlighted by the Royal Society of London to celebrate 350 years of scientific publishing — alongside articles spotlighting the scientific achievements of women specifically by the National Library of Scotland and the Dangerous Women project.[20] Alternative digital content includes exhibitions, such as 'The Women of Scotland' by Historic Environment Scotland where Somerville is listed as a STEM pioneer, and multiple podcasts including the BBC'S Discovery series; Somerville's final book *On Microscopic and Molecular Science* has the dubious honour of being featured in an episode of the podcast Boring Books for Bedtime Stories.[21] As well as Somerville College, she

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18 RBS ran a Facebook campaign where the British public could choose the scientist to be featured on their forthcoming polymer £10 note. Voters could choose between Thomas Telford, James Clerk Maxwell, and Mary Somerville by liking the picture of their favourite; it was a tight race between Somerville and Clerk Maxwell until eight hours before the deadline when thousands of likes were added to Telford's image by a bot in Asia. Luckily RBS chose to discount those votes, leaving Somerville the winner. See the *Oxford Sparks* podcast episode from 20/02/2018 https://tinyurl.com/Somerville-note-sparks accessed 09/05/2021.

19 See https://www.google.com/doodles/celebrating-mary-somerville, url accessed: 15/04/2021.

20 See: https://tinyurl.com/1826-magnetism-creativity accessed 11/05/2021; https://tinyurl.com/NLS-Somerville accessed 11/05/2021; https://tinyurl.com/dangerous-Somerville accessed 11/05/2021.

21 'The Women of Scotland' accessed via https://www.historicenvironment.scot/archives-and-research/online-exhibitions/the-women-of-scotland/ on 15/04/2021. See also 'George Airy and Nineteenth-Century Sciences accessed via

is now commemorated by the Mary Somerville Data Centre at Edinburgh University, a Committee Room at the Scottish Parliament, and the Institute of Physics recognises outstanding public engagement in physics by early career researchers with their Mary Somerville Medal.

A common thread running through much of the scholarship on Somerville is her aptitude for, and love of, mathematics. The first public recognition she received for her intellectual pursuits was the silver medal from the *New Series of the Mathematical Repository* she was awarded in 1811. Although her puzzle solution was published anonymously, under the pseudonym 'A Lady', the medal itself is engraved with her name (see section 2.2). Moreover, her introduction to the polite scientific society centered around London was as a mathematician; in her letters of introduction to astronomer William Herschel and science writer Jane Marcet she was distinguished for her acquirements in mathematics and her knowledge of algebra and geometry especially (see section 3.3). Although her most successful work was arguably *Connexion*, which did not cover recent mathematical research for its own sake, and a glance over her list of published works exhibits very little work in this area, much of Somerville's success as a scientific writer was predicated on her reputation as an expert mathematician. Neeley identifies Pierre-Simon Laplace's public approbation of Somerville after they met in Paris as the "foundation of her greatness", and in his 1834 review of *Connexion* William Whewell situated Somerville in a line of eminent female *mathematicians* including Hypatia and Maria Agnesi (Neeley, 2001, p. 20), (Whewell, 1834, p. 66). Moreover, Somerville's interest in the physical sciences was intimately related to her study of mathematics, as she felt that only those who could understand physical astronomy mathematically could appreciate the "extreme beauty" of the results in her *Mechanism of the Heavens* (Somerville, 1831, p. vii). It was analysis — "mathematical reasoning by means of abstract symbols" — which she saw as uniting the physical sciences, and which she described as the subject she preferred above all others (Somerville and Somerville, 1873, p. 202), (Somerville, 1834, pp. 413, 418).[22]

This thesis complements and adds to existing scholarship by investigating Somerville explicitly as a mathematician. Such a study shines a light on what type of work was recognised as worthy of the title mathematician by 19th-century practitioners in Britain. As noted

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https://tinyurl.com/Airy-exhibit on 09/05/2021. The Boring Books for Bedtime Stories episode aired December 9, 2019.

22 The definition for analysis given here is taken from the 'Explanation of Terms' appended to the end of the first edition of *Connexion*.

by Chapman, the scientific community of the time was not yet 'professionalized', but even the few opportunities there were for formal training or participation were closed to Somerville owing to her gender. She did not study mathematics at high school nor university, and unlike multiple other contributors to *The New Series of the Mathematical Repository* she did not find a job as a mathematics teacher or open her own school. As a woman, Somerville was effectively precluded from holding an official position at an observatory or university, and from holding an office of a learned society. Nevertheless, as suggested by Secord, Somerville was part of a network that only partly depended on print and so was able to cultivate her reputation in mathematics before she began writing books, and maintain a mathematical reputation when her publications strayed into other areas of science (Secord, 2014, p. 113).

1.3   THE DECLINE AND REFORM OF BRITISH MATHEMATICS

A consideration of the work valued by the mathematical community in the early-nineteenth century is especially pertinent owing to the widespread perception of a decline in British mathematics compared to the mathematics practiced on the continent, especially France (Ackerberg-Hastings, 2008). This supposed decline has been well treated, but Somerville's role in the reform movement and the influence this movement had on her own work has so far been little studied.

Sentiments of decline can be found in mathematical literature stretching from the late eighteenth century through to the 1830s, as will be witnessed throughout this thesis.[23] Perceived differences in the mathematical practices of France and Britain were frequently delineated through an appeal to notions of 'analysis' and 'synthesis' respectively, with the former being predominantly associated with algebraic investigations, and the latter with geometry.[24] As well as being used to describe forms of mathematical practice, the terms 'analysis' and

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23 A perception of decline in British science more broadly can also be witnessed in literature of this period, for example in 1830 John Herschel wrote the following in his article 'Sound' for the *Encyclopedia Metropolitana*: "whole branches of continental discovery are unstudied, and indeed almost unknown even by name [in Britain]... in Mathematics we have long since drawn the rein and given over a hopeless race. In Chemistry it is not much better... There are, indeed, few sciences which would not furnish matter for similar remark" (Herschel, 1845). See (Topham, 2011) for more on the circulation of French scientific texts in Britain at this time.

24 That these associations were imperfect is clear from (Bruneau, 2015) and (Lorenat, 2016) which discuss analytic methods of studying geometry in the early nineteenth century.

'synthesis' were also used to refer to differing styles of proof and pedagogy, which further divided the the French and British mathematical communities (Ackerberg-Hastings, 2002), (Richards, 1991).[25]

A key area in which reform was desired was in the calculus. As shown in (Guicciardini, 1989), throughout the eighteenth century research in the calculus in Britain had diverged from that undertaken in continental Europe, even though individuals certainly continued communicating and sharing results across the English Channel. Work in Britain was primarily carried out in the Newtonian or fluxional tradition of calculus, which was based on ideas of kinematics (intuitive ideas of motion) and the manipulation of algebraic series, whilst mathematicians on the continent cultivated differential calculus as first proposed by Leibniz.[26] The eighteenth century saw widespread dissatisfaction with the foundations of the calculus, both fluxional and differential, prompting mathematicians to propose numerous alternative conceptions which were either seen to be more metaphysically sound or methodologically fruitful. Guicciardini identified at least five different conceptualizations which he associated with the mathematicians Arbogast, Lagrange, Euler, Woodhouse, and Cauchy, respectively.[27]. Adherence to these different conceptions of the calculus had "suggest[ed] separate directions for research and therefore generate[d] different kinds of knowledge", creating further intellectual distance (Sigurdsson, 1992, p. 110). This distance visibly manifested in the mathematical notation used; the fluxional notation of Newton, $\dot{x}, \dot{y}$, was most prevalent in the work of British mathematicians, and the differential notation introduced by Leibniz, dy, dx, was referred to by them as the 'foreign notation'.

That this incongruity of mathematical practice was interpreted as an *inferiority* of British mathematics was owing to the abundant applications of differential calculus — especially calculus of variations and differential equations — to studies of the physical sciences. Somerville herself commented in *Personal Recollections* that "mathematical science was at a low ebb in Britain; reverence for Newton had prevented men from adopting the 'Calculus', which had enabled foreign mathematicians to carry astronomical and mechanical science to the highest

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25 For more on analysis and synthesis in the history of mathematics see (Pycior, 1989), (Otte and Panza, 1997), (Craik, 2000), and (Jahnke, 2003).

26 'Differential' is here used to distinguish between the two different styles of the calculus — differential and fluxional — present in the early nineteenth century rather than to suggest a restriction to methods of differentiation, or an omission of methods of integration or fluents. For a discussion on the discovery of the calculus and the ensuing priority dispute see (Sigurdsson, 1992, p. 98).

27 For more on the rigorization of the calculus see (Grabiner, 2012).

perfection" (Somerville and Somerville, 1873, p. 78). The work which has been identified as one of the main catalysts for the adoption of differential calculus in Britain was none other than Laplace's *Mécanique Céleste*, the very book which Somerville translated and adapted into her first book in 1831 (Guicciardini, 1989, p. 117), (Craik, 2016).

It is interesting to note that many mathematicians who saw themselves as importing analytical methods in order to combat the decline of British mathematics, described it as re-importing something that originally belonged to Britain, with either implicit or explicit references to Isaac Newton. This is seen in the preface to the memoirs of the Analytical Society of Cambridge, a key vector in the circulation of analytical mathematics in Britain, where the following assessment of the development of the calculus was given:

> Discovered by Fermat, concinnated and rendered analytical by Newton, and enriched by Leibnitz with a powerful and comprehensive notation, it was presently seen that the new calculus might aspire to the loftiest ends. But as if the soil of this country were unfavourable to its cultivation, it soon drooped and almost faded into neglect, and we have now to re-import the exotic, with nearly a century of foreign improvement, and to render it once more indigenous among us. (Anon, 1813, p. iv).

The political climate of the time, with the recent French revolution and the Napoleonic Wars, made it somewhat risky to openly avow the superiority of anything French. The French political and scientific communities (which were by no means distinct) were seen as a meritocracy, hence their military and intellectual successes threatened the ruling classes in Britain whose power relied on "the belief that men of land and birth were inherently more suited to the exercise of authority than any other social group" (Colley, 2003, p. 150). Moreover, the emergence of a distinctly 'British' identity, alongside or including English, Welsh, or Scottish, relied on Britons defining themselves collectively against an external, hostile 'Other', and the frequent wars with France throughout the eighteenth century led to Briton's defining themselves in opposition to the "superstitious, militarist, decadent and unfree" people of France (Colley, 2003, p. 5). Somerville was by no means free from anti-French sentiment herself. In 1817 she travelled to France for the first time, and during her trip she kept a diary. Here she described the seasickness she felt aboard the packet ship from Dover to Calais, and the vow she had taken to never again board a ship after she had safely returned to England.

However, by the time of writing her diary entry after she had landed in Calais, she admitted that her resolve was already weakening and asked herself: "does this sudden laxity of principle arise from French air?"[28]

The reformers of Newtonian calculus at the turn of the nineteenth century were grouped by Guicciardini into four schools, located in Scotland, Cambridge, Dublin, and the Royal Military Schools respectively. Professors of mathematics in Scotland such as Charles Hutton and John Playfair vocally advocated for the adoption of continental analysis and differential calculus, but were not able to mobilise it in their own research (Guicciardini, 1989, p. 112). The professors at the Royal Military Colleges, especially William Wallace and James Ivory, were able to go beyond rhetoric and produce novel research in analysis, but owing to the low level of mathematics that they were required to teach were not able to pass this knowledge on to their students (Craik, 1999), (Panteki, 1987). Similarly, the influence of the Analytical Society of Cambridge over the direction of analytical research in the mid-nineteenth century has long been appreciated, whilst their failure to enact real change in the *teaching* of mathematics at Cambridge has more recently been recognised (Enros, 1979), (Enros, 1983). Although analytical mathematics was seen as necessary for developing new results in mathematics, it was ancient geometry and synthesis which were viewed as suitable subjects for teaching students how to think, and the aim of the universities was to provide a liberal education for gentlemen, not to train research mathematicians (Warwick, 2003, p. 95), (Craik, 2007). There was an outcry in 1817 when differential notation was introduced into the Senate House Exams, and successful resistance to the domination of pure analysis in the Cambridge curriculum by William Whewell extended into the 1840s (Becher, 1980), (Warwick, 2003, p. 68).

Mary Somerville was at the centre of a network of mathematicians invested in reforming mathematical research in Britain, with connections to reformers in Edinburgh, Cambridge and the Royal Military Schools. Perhaps one of the few benefits of her exclusion from university was that she instead pursued a self-directed course of study which from the outset was heavily skewed towards recent French literature. An investigation of Somerville's path as a mathematician, broadly conceived to include her engagement with polite scientific society alongside her written works, provides a new insight into the circulation of French analysis in early-nineteenth-century Britain. More-

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28 MS, Dep. c. 355, MSAU–1. Somerville's diary covering her time in Paris is reproduced in (Patterson, 1985).

over, it demonstrates how knowledge of this esoteric and highly valued mathematics was leveraged by Somerville to overcome gendered barriers and build a scientific career.

1.4   PLAN OF THE THESIS

Following a roughly chronological route, this thesis explores Somerville qua mathematician, from her early studies and engagement with the philomath community, to her preparation of an introductory calculus textbook in her 90th year.

Chapter 2 begins with a re-evaluation of Somerville's introduction to mathematics and her engagement with the *New Series of the Mathematical Repository*. As well as leading to the first public recognition of her mathematical ability, by submitting solutions to mathematics puzzles published in the *Repository*, Somerville was able to forge a mentor-mentee relationship with a mathematician at the forefront of the reform movement. From letter correspondence and a notebook of Somerville's draft puzzle solutions, we witness both her training in this esoteric mathematics and the importance of her adoption of differential calculus to the building of her scientific network.

As a woman with limited financial means, Somerville was especially dependent on the mediation of others to access the spaces in which scientific knowledge was circulated. A key mediator was certainly her husband, William Somerville, and Chapter 3 explores the importance of his interventions and how they reflect on the gendered barriers to knowledge which existed at the time. Considering Mary and William Somerville through the lens of "collaborative couples" brings a new perspective to this growing area of research.

Returning to the question of the differing mathematical terrains of Britain and France, Chapter 4 scrutinizes the mathematical work which Somerville carried out when translating Laplace's *Mécanique Céleste*. Beyond translating between the languages of French and English, Somerville attempted to write a work that would maintain the spirit of the analytical mathematics used by Laplace, whilst being accessible to a British readership. From a consideration of the mathematics contained in *Mechanism of the Heavens* we can better understand the role it played in popularising and circulating Laplace's work.

Finally, Chapter 5 considers Somerville's involvement in mathematics after she stopped publishing in this discipline. Primarily focusing on two book-length manuscripts which were never published, and to which Somerville returned multiple times in her life, we consider

her motivations for writing these texts and for ultimately choosing to focus on new editions of her treatises on the physical sciences and geography rather than see these works through to completion.

MARY SOMERVILLE'S EARLY CONTRIBUTIONS TO THE CIRCULATION OF DIFFERENTIAL CALCULUS

Somerville's autobiography, published posthumously in 1873, has heavily influenced the narrative of her early life with most accounts relying on it almost completely (Strickland, 2016), (Chapman, 2015), (Neeley, 2001) and (Patterson, 1983).[1] However, whilst *Personal Recollections* is an invaluable biographical source, it provides little information on the mathematical resources Somerville had access to in her youth, nor her level of engagement with such texts. In order to supplement this account, we begin by considering Somerville's first known publications, which were solutions to mathematical puzzles published in the *New Series of the Mathematical Repository* during the 1810s. Somerville thereby joined a mathematical publication community centred around journals and periodicals, and was able to build a mentor-mentee relationship with William Wallace, a Professor of Mathematics at the Royal Military College (Despeaux, 2002, p. 7). A consideration of Somerville's draft solutions, contained in letters and notebooks, will be used to shine a light on her studies of analytical mathematics and to understand how, by 1817, she was able to read and *understand* Laplace's notoriously incomprehensible *Mécanique Céleste*.

2.1 AN AUTOBIOGRAPHICAL ACCOUNT

Although Somerville's childhood in the seaside town of Burntisland endowed her with a lifelong love of nature and wildlife, her formal education was very limited. She learnt to read the Bible with her mother and, in the hopes of reducing her "strong Scotch accent", Somerville's father made her read aloud a paper a day from *The Spectator*, a periodical published almost daily between March 1711 and December 1712 (Somerville and Somerville, 1873, pp. 17, 20).[2] She studied "the common rules of arithmetic" at a writing school, at-

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1 This chapter is derived from an article which appeared in *Historia Mathematica*, (Stenhouse, 2020).

2 The articles contained in *The Spectator* were republished in seven bound volumes between 1712 and 1713; these volumes were reprinted often throughout the eighteenth century in at least London, Edinburgh and Dublin and played a notable role in Scottish Enlightenment thought (Bond, Addison, and Steele, 1965, Vol 1, v), (Phillipson,

tended a village school for needlework, and spent a single year at a boarding school (Somerville and Somerville, 1873, p. 36). Somerville was very unhappy at this boarding school, describing herself as "a wild animal escaped out of a cage" when she was allowed to return to Burntisland and resume her explorations of the countryside and beaches where she collected shells and observed the starfish. She also claimed to have learnt very little at boarding school, and on her return disappointed her parents at her inability to "write well and keep accounts, which was all that a woman was expected to know" (Somerville and Somerville, 1873, pp. 24–25).

Somerville's discovery of algebra occurred when reading a ladies magazine with a certain 'Miss Ogilvie', who described the subject as "a type of arithmetic" (Somerville and Somerville, 1873, p. 47). She was initially unable to find any further information regarding algebra, as none of her immediate family had an interest in such things, nor would she have had the courage to ask them if they had for fear she "should have been laughed at". Somerville described herself at this time as "often very sad and forlorn, not a hand held out to help me" (Somerville and Somerville, 1873, p. 48). Whilst at a painting lesson with Alexander Nasmyth, she overheard him recommending reading Euclid to her fellow students, as it was "the foundation not only of perspective, but of astronomy and all mechanical science" (Somerville and Somerville, 1873, pp. 49–53). Feeling that it was impossible to go to a bookseller's herself, she had to wait until her brother's tutor purchased Euclid's *Elements* and Bonnycastle's *Algebra* on her behalf, which were the books used in schools at that time.[3] She proceeded to study these books independently at night—even after her candles were confiscated by her parents, who were most displeased at their daughter's night-time activities. Discouraged by her family members, Somerville recollected; "I felt in my own breast that women were capable of taking a higher place in creation than that assigned to them in my early days, which was very low" (Somerville and Somerville, 1873, p. 60). Undeterred, she would rise at day-break, wrap herself

1981, p. 26), (Broadie, 2003). This iteration of *The Spectator* is unrelated to the weekly magazine which bears the same name nowadays.

3 More than five English editions of Euclid's *Elements* were published in Britain in the eighteenth century; Robert Simson's 1756 *The Elements of Euclid* became a key mathematical textbook in Scotland, both in schools and universities and was reprinted 26 times by 1780 (Barrow-Green, 2006, pp. 10–3), (Ackerberg-Hastings, 2002, p. 48). John Bonnycastle, a mathematical master at the Royal Military Academy in Woolwich, first published his *An Introduction to Algebra* in 1782, and by 1824 it had reached its thirteenth edition (Whittaker and Rice, 2004), (Bonnycastle, 1782).

(a) Burntisland seafront.

(b) The view out to sea from Burntisland beach.

Figure 5: Photos of Burntisland beaches. Photographs the author's own, taken June, 2018.

in a blanket and "read algebra or the classics till breakfast time" (Somerville and Somerville, 1873, p. 65).

Somerville's isolation increased further on her marriage to her second cousin Samuel Greig (1778–1807) in 1804, with whom she moved to London. During this brief marriage she continued her mathematical studies "under great disadvantages" as she received no support from her husband, and she was separated from Edinburgh society by hundreds of miles. On the other hand, she recalled using this time to pursue her mathematical studies alone and to take lessons in French; perhaps already by this time she knew the importance of reading French mathematical texts in order to find the most advanced and up-to-date work. In addition, a 'Mrs Greig of Great Russell Street' subscribed to the Royal Institution (RI) on Albemarle Street in 1805 (Lloyd, 2019, pp. 209, 291). Somerville does not mention having visited the RI at this time in her life, but did live at 92 Great Russell Street with Greig, and one of only two acquaintances mentioned in her recollections was also a subscriber in the early 1800s.[4] Therefore Somerville attended lectures at the RI which covered topics from chemistry, to mechanics, to poetry. Greig passed away after only three years of marriage, and subsequently Somerville returned to her family home in Burntisland, a widow, and mother of two sons, with limited independent means. She there resumed her mathematical studies in earnest, and after studying "plane and spherical trigonometry, conic sections and... astronomy", turned to Isaac Newton's *Principia*, which she found "extremely difficult" on first reading (Somerville and Somerville, 1873, p. 78).

In a time when social standing and rank greatly determined one's prospects, Somerville benefited significantly from her place amongst the minor gentry. Through her mother, Somerville was distantly related to the Earl of Minto, and her father claimed to be connected to the Barons Fairfax of Cameron in the Scottish peerage (Somerville and Somerville, 1873, pp. 6–8). Although her immediate family were not themselves notably wealthy or amongst the peerage,[5] her father was knighted in recognition of his part in the 1797 Battle of Camperdown and was thus entitled to the prefix 'Sir'. As a physician, Somerville's second husband William Somerville (1771–1860) would

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4 Catherine Herbert, Countess of Pembroke, with whom Somerville attended the Italian Opera in London (Somerville and Somerville, 1873, p. 76). Herbert was not recorded as a subscriber until 1810, but Lloyd makes clear the limitations of the extant data on female subscribers in her doctoral thesis, so it is possible that she was also a subscriber during Somerville's time in London (Lloyd, 2019, p. 64).

5 Dukes, Marquesses, Earls, Viscounts, and Barons made up the peerage, whose titles were almost always hereditary.

have ranked amongst baronets and knights, and his family was thus entitled to be presented at the Queen's Drawing Room in St James' Palace; indeed in 1837 Somerville attended the coronation of Queen Victoria (Somerville and Somerville, 1873, pp. 148, 199).

By Somerville's account, she was welcomed into Edinburgh society from a young age, often sitting with ladies in their boxes at the theatre and attending both public and private balls; in preparation for these she had attended "Strange's dancing school", where she learnt reels and country dances whilst in full evening dress (Somerville and Somerville, 1873, pp. 43, 52). Her acquaintance with Nasmyth would have brought her into the same circles as the scientific and medical men of Edinburgh with whom he was intimately connected (Chapman, 2015, p. 17). Whilst out in Edinburgh society she became acquainted with a "small society of men of the most liberal principles" who conducted the *Edinburgh Review*. Somerville specifically mentioned Sydney Smith (1771–1845), a well-known author and moral philosopher, Henry Brougham (1778–1868), a lawyer (and later Baron Brougham and Vaux), and John Playfair (1748–1819), who held the chair of natural philosophy at the University of Edinburgh (Somerville and Somerville, 1873, pp. 63–5, 81–3). Playfair would later nominate William Somerville for membership of the Royal Society of Edinburgh, through which William and Mary Somerville became more closely acquainted with those interested in the sciences, both in Edinburgh and London (see section 3.1). After a brief mention of her solutions in the *Mathematical Repository*, the purchasing of advanced French mathematics texts, and advice given to her by Playfair for reading Pierre-Simon Laplace's *Traité de Mécanique Céleste* (Laplace, 1799–1825), mathematics receives little attention in PR until the narrative reaches the 1820s.

Beyond listing the titles of books that she purchased, Somerville's account in PR provides very little information on the extent of her engagement with mathematics up until the mid 1820s. She gave no details of how far she was able to progress in her reading, nor of any difficulties she faced in the mathematical content and how she overcame them. Although we learn much about her expanding social network, this is insufficient to explain how she transitioned from an isolated amateur to a mathematician recognised throughout Great Britain and Western Europe.

Moreover PR was written sixty years after the period in which we are interested, and presents a heavily curated view of Somerville's life. The narrative is deeply shaped by her desire to advocate for higher education for women and limited by the materials she had

to hand. It is clear throughout that Somerville was aware of her value as a symbol of scientific attainment in the 'fairer sex', as well as of the self-improvement which could be gained through the independent pursuit of knowledge (Secord, 2004, xi–xii, Vol 9). As mentioned in Chapter 1 this curation of Somerville as perfectly conforming to Victorian ideals of womanhood was furthered during the editing process of PR. Where Somerville was forced to rely on memory alone in the writing of her memoir, having no letter or notebook to which to refer, inconsistencies and inaccuracies were often introduced. For example, she claimed that whilst Augustus De Morgan had adopted the differential calculus, "several years elapsed before Mr. Herschel and Mr. Babbage were joint-editors with Professor Peacock in publishing an abridged translation of La Croix's[sic] *Treatise on the Differential and Integral Calculus*" (Somerville and Somerville, 1873, p. 78); but this translation was in fact published in 1816 when De Morgan was only 10 years of age (Lacroix, 1816).

Therefore we turn here to contemporary letters and notebooks to supplement Somerville's autobiographical account and present an expanded and more precise time-line of her early engagement with mathematics.

2.2   A MEDAL FOR MATHEMATICS

The earliest epistolary evidence we have of Somerville studying mathematics is a letter written to her by fellow Scot, John Wallace, in July 1811. Wallace is only briefly mentioned by Somerville in PR as an acquaintance who she engaged to read mathematics and physical astronomy books with her:

> ...as I never had been taught, I was afraid that I might imagine that I understood the subjects when I really did not; so by Professor [William] Wallace's advice I engaged his brother to read with me... Mr. John Wallace was a good mathematician, but I soon found that I understood the subject as well as he did. I was glad, however, to have taken this resolution, as it gave me confidence in myself and consequently courage to persevere (Somerville and Somerville, 1873, p. 82).

Little seems to be known about John Wallace. He has no entry in the *Dictionary of National Biography* nor the *Dictionary of Scientific Biography*, nor does he appear in the entries of his older brother William Wallace (who will be discussed in more depth in Section 2.3). The

records of the Royal Military College[6] show that John Wallace was hired as the Master of Arithmetic there in September 1817, aged 36, and remained in post until 1823 when he succeeded to the ministry of a Scottish Parish.[7]

John Wallace begins his letter by apologising to Somerville for failing to reply to her last communication, but he is "confident that all excuses are unnecessary" as he has "the pleasure of informing [Somerville] that [her] solution of the prize-question for the Mathematical Repository has gained the prize".[8]

The 'Mathematical Repository' mentioned here was in fact the *New Series of the Mathematical Repository* (MR). Edited by Thomas Leybourn, master of mathematics at the Royal Military College where John Wallace would later work, MR was published in six volumes at irregular intervals between 1806 and 1835 (Guicciardini, 2004). Each volume was divided into three parts: one of 'Original Essays on Mathematical Subjects'; one of 'Mathematical Memoirs, extracted from Works of Eminence'; and finally questions 'in almost every branch of mathematics' together with their solutions as submitted by readers (Leybourn, 1806–1835, Advertisement, Vol 1). In 1814, from the third volume onwards, a fourth part was introduced entitled 'Cambridge Problems', in which questions from the Senate-House examination at the University of Cambridge were reproduced (Leybourn, 1806–1835, 1, Section 4, Vol 3).[9]

The question and answer section in each volume contained up to 120 questions, separated into four 'Numbers' of around 30 questions each. It seems that these numbers were circulated separately before being issued in the bound volumes, as, for example, Number IV contained the solutions to the questions printed in Number II, with both Numbers II and IV contained in Volume 1.[10] Each Number concluded

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6 The Royal Military College was based in Great Marlow, near London, and subsequently in Sandhurst from 1812 until its closure in 1939. In 1947 the Royal Military Academy was subsequently founded on the same site in Sandhurst.

7 The Sandhurst Collection, Royal Military College (RMC) Staff Register (1802–1939), page 142, viewed at www.sandhurstcollection.co.uk (paywalled).

8 MS, Dep. c. 375, Folder MSDIP–1, John Wallace to Mary Greig, 12/07/1811.

9 This was the examination students sat to earn their Bachelor of Arts degree. After 1822 the Senate House examination was also referred to as the Mathematical Tripos; for more information on the examination system at Cambridge see (Warwick, 2003, pp. 52–8). Collections of the Senate-House questions were sometimes published in separate volumes, for example (Wright, 1836) and (Anon, 1837).

10 The practice of publishing mathematical questions and answers submitted by readers in almanacs and periodicals can be traced back to the beginning of the eighteenth century; Despeaux has identified almost forty works which contain such sections published in Britain during the eighteenth and nineteenth centuries (Despeaux, 2014, p. 55). Of these, the *Ladies' Diary* is perhaps most well known. Founded in 1704, it

with a final question designated as a 'Prize Question', for the best solution of which the editors would award a specially cast silver medal, followed by a selection of 'Notices relating to Mathematics'. The Prize Questions do not differ tangibly from the other problems included in MR, either by content or difficulty. Both were submitted by a variety of contributors, from professors of mathematics at the Royal Military College to provincial gentlemen, with many submitted under pseudonyms.[11] One puzzle was extracted from a memoir of Gauss (Prize Puzzle 490, Number XIX, Volume 5), and solutions to at least two questions (Prize Puzzle 390, Number XIV, Volume 4 and 430, Number XVI, Volume 5) were extracted from the *Annales de Mathématiques pures et appliquées*.[12]

Mathematical periodicals with Q&A sections, such as MR, played a key role in the education and careers of those whose means precluded them from school or university, as demonstrated in the life of contributor John Butterworth, an autodidact who went on to supplement his income by solving mathematical puzzles for others and ultimately opened a school (Despeaux, 2014, p. 17). Other contributors built a name for themselves through submitting their solutions to periodicals, and then went on to become staff members at the Royal Military College. These included James Cunliffe, who we will meet again later, who submitted questions and solutions to both MR and the *Ladies' Diary* before being hired in March 1805 as a Master of Arithmetic, and then promoted in 1819 to a Professor of Mathematics.[13] Similarly John Wallace himself submitted solutions to MR and was later hired by the college.

At this time, the posing and answering of mathematical puzzles in such periodicals was consciously seen by practitioners as a way to actively contribute to mathematical knowledge. Q&A sections were included in periodicals and journals throughout Western Europe in

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ran for 136 years and contained mathematical questions alongside word puzzles, calendars with notable dates, and lists of upcoming eclipses. Puzzles were both submitted and answered by women, and when retrospectively categorised in 1817 the questions covered topics such as algebra, geometry, fluxions, hydrostatics, optics and more (Perl, 1979, pp. 37–9). See also (Costa, 2002) and (Albree and Brown, 2009).

11 One such provincial gentleman was a Mr Mason of Scoulton, "a gentleman whose labours... enriched the English periodicals for several years" (Anon, 1836, p. 25). Submissions for the Q&A section came from readers across Great Britain and Ireland, including Birmingham, Bolton, Carlow, Dublin, Edinburgh, Liverpool, London, and Plymouth.

12 The *Annales* was a mathematical journal edited by Joseph Diez Gergonne (1771–1859) and published in Nimes, France from 1810–1831, see (Barrow-Green, 2013, p. 74). The journal is commonly known as Gergonne's *Annales*.

13 The Sandhurst Collection, Royal Military College (RMC) Staff Register (1802–1939), page 021, viewed at www.sandhurstcollection.co.uk (paywalled).

the eighteenth and nineteenth centuries and, as we will see in the case of MR, contained highly advanced and innovative mathematics (Despeaux, 2014, pp. 47–50). According to the Advertisement of the first volume of MR

> The utility of this part of the work [the Q&A section] will be readily admitted when it is considered, that almost all the improvements which the Mathematics have received, have originated in the exertions made to resolve particular problems, such as that of the *trisection of an angle* among the ancients; also the various *isoperimetrical problems*, and above all, the problem of *the three bodies* among the moderns. We believe also, that most Mathematicians will confess how much their talents have been cultivated and their knowledge improved, by resolving problems, such as are proposed in this volume (Leybourn, 1806–1835, Advertisement, Vol 1).

Thus when Somerville chose to submit a solution to the *New Series of the Mathematical Repository*, she was engaging in a well-established and highly valued mathematical practice, and moving from a passive consumer of knowledge to an active contributor.

John Wallace's delight and pride in Somerville being awarded a silver medal for her MR submission are evident in his aforementioned letter.[14] His subsequent description of her as his "pupil" in the same letter indicates he had a much more formative influence on her mathematical studies than Somerville's account of him as a mere reading companion would otherwise suggest. It is very unlikely that Wallace is here implying Somerville paid him for private tutoring. More probable is that they became acquainted in Edinburgh society, and on discovering a shared interest in mathematics pursued a closer acquaintance which developed into that of informal mentor and mentee.[15]

However, although John Wallace announced to Somerville that her solution had been selected for a prize, and we still have the medal which Somerville was awarded (see Figure 6), no contributions appear in any volume of this periodical under the name Mary Fairfax, Greig or Somerville. Just over a month before Wallace's letter, on June 1 1811, submissions had closed for solutions to Questions 291–310, which were subsequently published in Volume 3 of MR in 1814 (Leybourn, 1806–1835, Vol 3). A handwritten copy of the winning solution

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14 MS, Dep. c. 375, Folder MSDIP–1, 12/07/1811.
15 We see this process again later in Somerville's life through her informal tutoring of Ada Lovelace, see section 3.2.

Figure 6: The medal awarded to Mary Somerville for her solution of Prize Question 310, posed in Volume 3 of MR. The medal is now held at Somerville College, Oxford and the inscription reads: Maria Greig, L.M.D; PALMAM QUI. MERUIT FERAT; T. Leybourn. L.M.D stands for Libens merito dedicavit, and the Latin loosely translates as 'deservedly won; let they who have earned the palm, bear it'. The palm signifies victory.

to Prize Question 310 held in the Somerville Collection, suggests that Somerville's contributions were published under the pseudonym "a Lady" (Secord, 2004, xlv, Vol 1).[16]

As mentioned above, solutions were often published under pseudonyms, with some authors publishing under multiple identities as well as their own name. It is currently unknown why Somerville's solutions were published anonymously, but it is clear that they were not *submitted* under a pseudonym as in his letter John informed her that his brother had recently arrived in Edinburgh having set off from Marlow thirteen days previously, just after receiving her solution. His older brother William Wallace worked alongside Leybourn, the editor of MR, at the Royal Military College and so it seems likely that Somerville's solution made its way to Leybourn via William.[17] In addition, her medal from the editors clearly bears the name Maria Greig, so Somerville's identity was by no means a well-kept secret.[18]

Both Somerville and John Wallace continued submitting solutions to mathematical puzzles. (Secord, 2004) suggests that it is unlikely

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16 The handwritten solution is held in MS Dep. c. 372, Folder MSW–1; for the question see A.1.

17 William Wallace was also a frequent contributor to the journal and published under his own name as well as the pseudonyms Hypatia, X, Peter Puzzle, G.V., and Edinburgensis (Craik, 1999, p. 245).

18 Somerville's name appears in Latin as Maria Greig, as she had not yet married for the second time and assumed the name Somerville.

multiple people would have shared the same pseudonym, and subsequently we shall see manuscript evidence that all five solutions published in MR under the pseudonym "a Lady" were in fact written by Somerville. In addition, she prepared solutions to a further three questions, one of which provides the first written record of her usage of the differential calculus.

2.3   STUDYING THE CALCULUS

The *New Series of the Mathematical Repository* provided its readers with access to continental mathematics through a series of 'Notices Relating to Mathematics' which were consistently international in their outlook. For example, Volume 1 contained an announcement of the Prize Question of the Institut de France regarding the "Theory of the Perturbations of the Planet Pallas", whilst Volume 3 listed the authors and titles (translated into English) of all mathematical papers contained in the first 15 numbers of the Journal d'École Polytechnique. There were also announcements of recently published 'foreign books' (predominantly published in French), and later volumes contained obituaries of mathematicians such as Joseph-Louis Lagrange (1736–1813), Pierre-Simon Laplace (1749–1827) and Gaspard Monge (1746–1818). Another regular section of MR titled 'Works of Eminence' featured an anonymous translation of a 1798 work on 'spherical triangles' by Lagrange (Lagrange, 1798), and of a 1794 'memoir on elliptic transcendentals' by Adrien-Marie Legendre (Legendre, 1794); William Wallace is identified as the translator of both these works in (Panteki, 1987, p. 121).

Some of the first examples of differential notation as used by mathematicians working in Britain can be found in the Q&A section of MR. As such, it was described as "one of the most important works in the reform of the British Calculus" in (Guicciardini, 1989, p. 116). As early as 1809, Volume 2 contained four solutions which utilised differential notation, three of which were submitted by James Ivory (1765–1842), a Professor at the Royal Military College in Marlow.[19]

The fourth solution was submitted by William Wallace. Similarly to Somerville, William's mathematical studies had begun later in his life; as a bookbinder's apprentice in Edinburgh he pursued learning inde-

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19 See Questions 151, 160, 172 (Leybourn, 1806–1835, 65–124, Vol 2), as identified in (Panteki, 1987, p. 123). Ivory was later recognised throughout Europe for his work on the attractions of ellipsoids, published in the *Philosophical Transactions* of the Royal Society in 1809 (Michel, 2020, p. 138), (Craik, 2016, p. 250), (Anderson and Grattan-Guinness, 2005).

pendently, before attending the lectures of John Robison at Edinburgh University. Through Robison he was introduced to John Playfair, who in 1794 recommended him for the position of mathematical teacher at Perth Academy. William Wallace moved to the Royal Military College, Marlow in 1803, where he worked alongside James Ivory and, from 1817, his brother John.[20] In 1819, William Wallace left the RMC to take up the chair in mathematics at Edinburgh University, where he remained until he retired from ill health in 1838 (Stronach and Panteki, 2004).

It is possible that Somerville became acquainted with the Wallace brothers through Playfair, their mutual acquaintance. Although Somerville once described herself as "a pupil of Dr. Playfair", little evidence remains of their relationship either social or mathematical (Warner, 1855, p. 380). A single undated letter from Playfair to Somerville is held in the Bodleian collection; highly formal, Playfair here informed her of his intent to call on "Mrs. Somerville" the following Monday at her residence on Northumberland Street, Edinburgh.[21] As mentioned above, in PR Somerville recalled discussing her difficulties in reading *Mécanique Céleste* with Playfair between her two marriages, and in a letter of introduction for the newlywed Somervilles in the summer of 1812 he vouched for her aptitude in algebra, geometry, and astronomy (see section 3.1).

William Wallace's work on the differential calculus, and his translations of French mathematics are well treated in (Guicciardini, 1989), (Panteki, 1987), and (Craik, 1999). He certainly saw his adoption of differential notation as an act of reform. In c.1834 he penned a letter to George Peacock (1791–1858), a founding member of the Analytical Society who went on to become a mathematics lecturer in Cambridge, in response to the latter's *Report on Certain Branches of Analysis* (Peacock, 1834). In his letter Wallace objected that Peacock had left out notable contributions to reform which had been made outside of "Cambridge, the Holy City of Mathematics" (Panteki, 1987, pp. 123–4). Wallace specifically noted his own aforementioned translation of Legendre, and puzzle solutions published in MR in which he employed the "foreign notation" in a "revolutionary spirit" (Panteki, 1987, pp. 123–4). Wallace reiterated the importance of his usage of this notation when writing to Henry Brougham in May of 1835 to request support for his petition for a pension from the British government. Amongst a list of his achievements, including his contributions

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20 For more information on the role of the Royal Military College in the circulation of the differential calculus see (Guicciardini, 1989, pp. 114–5).

21 MS Dep. c. 371, MSP–4 272, John Playfair to Mary Somerville, undated.

to encyclopaedias and the invention of mathematical instruments, he explicitly noted that he and James Ivory, "were the first to introduce the Notation of the Continent into Britain in our writings" (Craik, 1999, pp. 262–3).

Somerville's first solution which used the differential calculus is contained in a letter written by her to William Wallace, in April of 1812.[22] The highly formal tone of this letter, written in third person, suggests that Somerville and William Wallace were still not yet personally acquainted. Furthermore, Somerville began the letter by thanking Wallace for the "handsome manner in which he interested himself" in her medal-winning solution, when he facilitated its publication nine months earlier, so this could perhaps have been only their second interaction.[23] Somerville enclosed in the letter her solutions to three questions posed in Number XI of MR. Two of these were later included or given an honourable mention in Number XIII under the pseudonym "a Lady", alongside her prize winning submission; they were solutions to Question 317 which treated a construction in Euclidean Geometry, and Question 311 which presented a problem in number theory and was solved using basic algebraic manipulation (see A.1).[24]

It is the third solution enclosed with the letter which provides our first view of Somerville using the differential calculus, as applied to the following question, submitted by John Lowry:[25]

XIV. Question 324,[26] *by* Mr. Lowry

With what radius must a circle be described, from a given point as a centre, so that intersecting another circle given by position, the length of the arch [sic] intercepted by the given circle may be a maximum?

In order to answer this question, Somerville deduced an expression for the arclength in terms of the radius of the circle given by

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22 This letter is part of a private collection of manuscripts once belonging to William Wallace, which was brought to the attention of John O'Connor and Alex Craik in 2011. Copies of those items which were deemed to have mathematical interest were subsequently made available via MacTutor (Craik and O'Connor, 2011, p. 17).

23 Letter held in a private collection. Mrs Greig to William Wallace, 16/04/1812. Accessed online 22/04/2021: https://mathshistory.st-andrews.ac.uk/Wallace/.

24 Both Numbers XI and XIII were published in Volume 3 of MR.

25 John Lowry was also a Master of Arithmetic at the Royal Military College, Marlow (Platts and Tompson, 2004).

26 The double numbering system in the Q&A sections is used throughout MR; the Roman numeral signifies that this is the fourteenth question in the specific Q&A section, whilst the Indo-Arabic numeral signifies it is the 324th question published in MR.

position, and the length of the chord which begins at a point of intersection of the two circles and meets the line connecting their centres at right-angles. This expression is given in the form of an integral, which Somerville argued must be a maximum. She then applied a variational method and found that this chord is in fact a diameter. Unfortunately a page of the letter is missing, so Somerville's solution is incomplete. What remains demonstrates Somerville's adherence to differential notation, alongside some conceptual misunderstandings of the question (Craik and O'Connor, 2011, p. 21).

It is unclear where or how Somerville would have studied the calculus of variations, but this solution certainly suggests that she had access to advanced mathematical texts before corresponding with William Wallace, perhaps through his brother John Wallace, or John Playfair. A possible text for Somerville to have read is Robert Woodhouse's 1810 *Treatise on Isoperimetrical Problems and the Calculus of Variations*, which would have been recently printed in Cambridge. Woodhouse claimed that his treatise brought together for the first time disparate results in the study of maxima and minima, or the "calcul des variations", from both British and continental authors, and rendered them understandable to a modern reader (Woodhouse, 1810, pp. i–iv).[27] However Craik notes that the work "addressed advanced analytical topics and so [was] at first read by few" (Craik, 2016, pp. 245–6). In PR Somerville claims to have purchased Euler's fundamental book on maxima and minima (Euler, 1744) but not until after corresponding with William Wallace. This text would also have been insufficient on its own, as the δ-notation used by Somerville in her solution was not introduced until 1762 by Lagrange (and subsequently adopted by Woodhouse amongst many others) (Lagrange, 1761–2) (Fraser, 2003, p. 361).

Although nearly half of the 90 questions included in Volume 3 were answered using calculus of some sort, only thirteen solutions used a form of differential notation, and even then it was often intermingled with fluxional language. Furthermore, eight of those solutions were submitted by William Wallace himself.[28] Thus it was perhaps quite a

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27 For more on Woodhouse in the context of the reform of British calculus see (Guicciardini, 1989, pp. 126–130).

28 William Wallace (under various pseudonyms) used differential notation in his solutions to Questions 263, 271, 279, 290, 298, 301, 306, 330. The other solutions which used differential calculus in volume 3 were submitted by: Reverend John Toplis to Question 252; Mr J Wallace, Edinburgh to Question 266 (this could have been the same John Wallace who was Somerville's mentor); Z's solution to Question 270; Messers Kyn and Williams to Question 297; and A.B.'s solution to Question 300 (Leybourn, 1806–1835, Vol 3).

surprise to receive a letter containing this style of mathematics, and from a woman no less. Although there is evidence that John Wallace was also interested in adopting differential notation, namely his solution to Question 266 in Volume 3 of MR, it could have been at this point that Somerville felt she had outgrown his tutelage, as she claimed in PR.

Certainly Somerville and William Wallace became much more closely acquainted almost immediately after this letter; whilst travelling to Portsmouth as a newly-wed in July of 1812 Somerville visited Wallace at the Royal Military College. Furthermore, Somerville suggests in PR it was to William Wallace that she turned for advice when beginning her private collection of mathematical books. He supposedly provided a list of works, mostly in French, for Somerville to read in order to fulfil her intention of following "a regular course of mathematical and astronomical science, even including the highest branches"; she specifically noted

> La Croix's *Algebra* and his large work on the Differential and Integral Calculus, together with his work on Finite Differences and Series, Biot's *Analytical Geometry and Astronomy*, Poisson's *Treatise on Mechanics*, La Grange's *Theory of Analytical Functions*, Euler's *Algebra*, Euler's *Isoperimetrical Problems* (in Latin),[29] Clairault's [sic] *Figure of the Earth*, Monge's *Application of Analysis to Geometry*, La Place's *Mécanique Céleste*, and his *Analytical Theory of Probabilities* &c., &c., &c.... (Somerville and Somerville, 1873, p. 79).

Many of the works mentioned here as being part of Somerville's original collection (to which she added substantially over the following sixty years of her life) are still held together at Girton College, originally a higher education institute for women which is now a mixed college at the University of Cambridge.[30] It is unclear how Somerville was able to purchase copies of these books, but from an inscription in her copy of Sylvestre-François Lacroix's *Traité du calcul différentiel et du calcul intégral* it appears she began purchasing the books as early as October 1812.[31] Certainly some of the texts were gifted to her, as Somerville's copy of another key work in late eighteenth century differential calculus, Joseph-Louis Lagrange's *Théorie des Fonctions Ana-*

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29 Euler's *Isoperimetrical Problems* would appear to be (Euler, 1744).

30 Surprisingly, one of the texts not in the Girton Collection is Laplace's *Traité de Mécanique Céleste*. Woodhouse's aforementioned *Treatise on Isoperimetrical Problems* (Woodhouse, 1810) was part of the collection, but it is unknown when she purchased this work, Girton College Library: Somerville Collection (073150).

31 Girton College Library: Somerville Collection (073122 & 073123).

lytiques... (Lagrange, 1797), bears inscriptions of both her name and that of William Wallace.[32]

Somerville was not blind to the importance of owning or having access to a mathematical library; in PR she reflected on the "long course of years in which [she] had persevered almost without hope" between first reading the "mysterious word Algebra" and finally acquiring what she described as the means to pursue her studies with "increased assiduity" (Somerville and Somerville, 1873, p. 80). Moreover, her mathematical library was left to Girton College on her death so that her books could continue to benefit women interested in higher mathematics (Somerville and Somerville, 1873, p. 80).

It is unclear to what extent Somerville would have been able to engage with these texts in 1812. Early on in PR she mentioned that she studied French whilst living in London with her first husband between 1804 and 1807, and that when visiting Paris in 1817 she "was less at a loss on scientific subjects, because almost all [her] books on science were in French" (Somerville and Somerville, 1873, p. 109). However, later on she claimed she felt "embarrassment and mortification... suffered from ignorance of the common European languages" which led her to engage language tutors for her daughters from a young age (Somerville and Somerville, 1873, p. 157). In addition, many of these texts were deemed too difficult even for highly trained mathematicians. Playfair wrote in 1808 that "a man may be perfectly acquainted with everything on mathematical learning that has been written in this country [Great Britain], and may yet find himself stopped at the first page of the works of Euler or D'Alembert... from want of knowing the principles and the methods which they take for granted as known to every mathematical reader". Regarding Laplace's *Mécanique Céleste* itself, Playfair estimated that no more than a dozen people in Great Britain could "read that work with any tolerable facility" (Playfair, 1808, p. 281). In order to investigate Somerville's engagement with and understanding of the differential calculus, we now turn to her correspondence with William Wallace in 1816.

2.4   USING THE DIFFERENTIAL CALCULUS IN PUBLISHED SOLUTIONS

Two letters written by William Wallace to Somerville in May of 1816 — by which point she was living in London with her second husband — further illuminate their relationship and Somerville's contri-

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32 Girton College Library: Somerville Collection (073119).

butions to MR.[33] In these letters Wallace offered criticism on work Somerville had previously shared with him, as well as enclosing further exercises on "the application of analysis to geometry", claiming that "such exercises [are] useful to prepare for the study of analytical works".[34] Wallace provided Somerville with his own solutions to the exercises that he set, sent concurrently in a sealed envelope, and for one exercise that Somerville had already completed sent her a solution "different, but not better", which he informed her was taken from the *Annales de Mathématiques pures et appliquées*.[35] Unfortunately Wallace's solutions mentioned in the letters are no longer extant.

Beyond providing materials for Somerville to use in her studies, William Wallace offered advice for developing good mathematical practice. He wrote:

> I hardly ever resolved a problem in the most direct manner possible at first: In general I find that a first solution may be improved and shortened, hence it always happens that a short and simple solution is the result of long meditation.

Wallace also strongly discouraged her from peeking at the solutions he sent before she had solved a question on her own.

In these letters, Wallace kept Somerville updated on the ongoing ill health of his daughters, sharing his sorrow at the slow improvement of his eldest daughter, demonstrating that in the preceding four years their acquaintance had developed into friendship, as well as that of informal mentor and mentee. When cataloguing her letters in the 1860s Somerville wrote the following note to accompany her letters from Wallace:

> My correspondence with Mr Wallace began when he was
> Professor at the Military College at Marlow in consequence
> of problems given in the Mathematical Repository which
> I sometimes succeeded in solving & sometimes not. Mr

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33 Along with a letter written by William Wallace in 1831, thanking Somerville for a copy of her *Mechanism of the Heavens*, and the aforementioned letter from Somerville to Wallace in 1812, these are the sole extant letters from the Somerville-William Wallace correspondence. MS, Dep c. 372, Folder MSW–1 and see Appendix B.

34 MS, Dep c. 372, Folder MSW–1, 12/05/1816 & 18/05/1816.

35 MS, Dep c. 372, Folder MSW–1, 18/05/1816. It seems that a volume of the *Annales de Mathematiques* had been seen by both William Wallace and his colleague Thomas Leybourn at the RMC, as solutions taken from the *Annales* were inserted in Volume 4 of MR in 1819 (see section 2.2). Copies of the journal were available to read in Cambridge at around this time, as they are mentioned in the memoir of a Cambridge student who sat the Tripos in 1818 (Wright, 1827, Vol 2, 27). It is currently unclear whether Somerville herself would have had direct access to this journal in London.

> Wallace sent his own solutions to me with criticisms on mine... I can never forget his kindness.[36]

As discussed earlier, three solutions by Somerville were included or mentioned in the third volume of MR, published in 1814, under the pseudonym "a Lady". That Somerville was in fact behind all instances of this pseudonym is supported by a handwritten copy of the prize question (with solution) amongst the William Wallace letters in the Somerville papers, and copies of the remaining two solutions in a letter written by Somerville to Wallace in 1812. Three further solutions by "a Lady", to Questions 377, 381, and 382 respectively (see A.2), were included in Volume 4, published in 1819. Wallace's letters mention Somerville's solution to one of these questions, Question 381 on the area of a lemniscata, as well as an attempted solution to Question 384 (see A.3 and below). Unfortunately neither Wallace nor Somerville's solutions are included with the letters; however, alternative copies of Somerville's solutions can be found in one of her personal notebooks dating from the early 1820s.[37]

Somerville's notebook contains a series of scientific and mathematical investigations dated between 1821 and 1824, including a diagram of Encke's comet and investigations on the undulatory theory of light.[38] Rather than making hasty jottings of ideas, Somerville here appears to have collected together neat summaries of both her own and others' work. Copies of her solutions to seven questions contained in Volumes 3 and 4 of MR are the first entries of the notebook, along with four miscellaneous mathematical puzzles with solutions. These entries include all the solutions published by "a Lady", except for Question 311, and solutions to three further questions included in Volume 4, namely questions 332, 384, and 387 (see A.3). These entries will be considered in conjunction with Wallace's letters to analyse Somerville's understanding of the calculus in 1816.

The first letter opens with Wallace's feedback on Somerville's attempted solution to "the 14th Question of the 14th No of the Math-

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36 Note written by Somerville c.1870. MS, Dep. c. 372, Folder MSW–1.

37 MS, Dep. c. 352, Folder MSSW–5.

38 In 1818 Johann Franz Encke calculated the orbit of a new comet, identifying it with observations made in 1786, 1795 and 1805. He was also able to predict the return of the comet, since designated 'Encke's Comet', and it was indeed observed by Christian Rümker in Sydney, Australia on 2nd June 1822. In recognition of his work, described as "the greatest step that had been made in the astronomy of comets since the verification of Halley's Comet in 1759", Encke was awarded the Gold Medal of the Astronomical Society of London (later the Royal Astronomical Society) in 1824 (Pritchard, 1866, p. 131).

ematical Repository", submitted by Paul Lawrence Baker under the pseudonym 'Palaba'[39]:

XIV. QUESTION 384, *by* Palaba

> Find the equation of the curve of which this is the property: if from a fixed point in the axis a perpendicular be drawn to it and produced to meet a tangent to any point in the curve, the length of this perpendicular and tangent together, shall be double the length of the curve between the vertex and the point from which the tangent was drawn.

Wallace began by noting that Somerville had misused a formula given by himself in item 77 of his *Edinburgh Encyclopaedia* article entitled 'Fluxions' (Wallace, 1815, p. 424). It is interesting to note that Somerville had thus clearly read this article, which played a key role in the circulation of the calculus in Great Britain in the early 19th century. Indeed Guicciardini described it as "the first complete English treatise on the calculus written in differential notation" (Guicciardini, 1989, p. 120).[40] Similarly to her 1812 solution to Question 324 discussed earlier, Somerville here demonstrated an awareness of and engagement with contemporary literature, but also conceptual misunderstandings of the mathematics in use. With his second letter, Wallace enclosed his own solution to the question (no longer extant) and encouraged Somerville to try again. He advised her to "avoid angular functions and to employ in [her] solution only the coordinates x, y and the arc z", and to replace $\frac{\partial y}{\partial x}$ with the symbol p for ease of calculation.[41] In addition, Wallace gave Somerville a criterion that the curve should satisfy so that she may know when she had the correct solution:

Let the curve meet the axis at A and C, where $3AB = BC$, then

$$3BC \times PQ^2 = BQ \times QC^2 \tag{1}$$

(see Figure 7).

The very first entry in Somerville's notebook is a solution to Question 384 (see Figure 8), and it is clear that this solution was prepared after May 1816 as Somerville follows both of William Wallace's suggestions above.[42] Using the notation from the diagram drawn by

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39 I am grateful to Olivier Bruneau for this identification; unfortunately little biographical or mathematical information about Baker is known at this time.

40 Although published as an entry in the *Edinburgh Encyclopaedia*, the article was 86 pages long and thus easily warrants being described as a treatise!

41 MS, Dep c. 372, Folder MSW–1, 18/05/1816.

42 MS, Dep. c. 352, Folder MSSW–5. Unfortunately the solution which Somerville originally sent to Wallace, and which prompted his critique, is not contained in the Somerville Collection in Oxford.
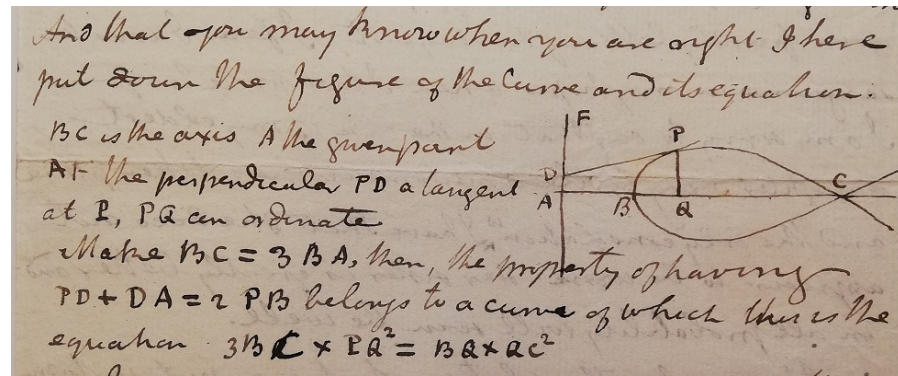
Figure 7: Extract of Willam Wallace's letter to Somerville, dated 18th May 1816, including his hint for answering Question 384, posed in Volume 3 of MR.

Somerville in her notebook solution (top of Figure 8), Question 384 asks for the equation of the curve BPG such that $AD + DP = 2BP$. Somerville began her solution by letting $AB = a$, $BQ = x$, $PQ = y$, and $BP = z$. Here BP is the curve connecting B and P, such that $PC = dz$. Somerville investigated the lengths of AD and PD by constructing triangle PFC with side lengths $PF = dx$ and $FC = dy$. By similar triangles, $AD = y - \frac{(a+x)dy}{dx}$. By the Pythagorean Theorem she deduced that $DP^2 = DE^2 + EP^2$ and $dz^2 = dx^2 + dy^2$. Hence $DP^2 = (a+x)^2(1 + \frac{dy^2}{dx^2}) \implies DP = (a+x)\frac{dz}{dx}$. Therefore $AD + DP = 2BP$ became $y - \frac{(a+x)dy}{dx} + \frac{(a+x)dz}{dx} = 2z$, the differential equation for the curve given.

Following Wallace's hint and letting $p = \frac{dy}{dx}$ and $q = \frac{dz}{dx}$, Somerville took differentials once and rearranged the equation into the form $\frac{dx}{a+x} = \frac{dq}{q} - \frac{dp}{q}$. As $q^2 = \frac{dz^2}{dx^2} = \frac{dx^2+dy^2}{dx^2} = 1 + p^2$, this could be rewritten $\frac{dx}{a+x} = \frac{dq}{q} - \frac{dp}{\sqrt{1+p^2}}$ which she integrated to get

$$\log(a+x) = \log(\sqrt{1+p^2}) - \log(p + \sqrt{1+p^2}) + \log c.$$

After removing the logarithms she got

$$a + x = \frac{c\sqrt{1+p^2}}{p + \sqrt{1+p^2}}.$$

Somerville claimed that as p is "infinite" when evaluated at the vertex B, where $x = 0$, then at this point "1 may be neglected in comparison of p", giving

$$a + 0 = \frac{c\sqrt{1+p^2}}{p + \sqrt{1+p^2}} = \frac{c\sqrt{p^2}}{p + \sqrt{p^2}} = \frac{c}{2}.$$

Therefore $c = 2a$ and

$$a + x = \frac{2a\sqrt{1+p^2}}{p + \sqrt{1+p^2}}.$$

Let $AB = a$, $BQ = x$, $PQ = y$, $BP = z$, then $PF = dx$, $FC = dy$.

It is evident that $DE : EP :: PF : CF$ hence

$PE = \dfrac{DE \times CF}{PF} = \dfrac{(a+x)dy}{dx}$ Consequently $AD = PQ - PE$ becomes

$AD = y - \dfrac{(a+x)dy}{dx}$. ____ Again, $DP^2 = DE^2 + EP^2$ or

$DP^2 = (a+x)^2 + (a+x)^2 \dfrac{dy^2}{dx^2} = (a+x)^2 \left(\dfrac{dx^2 + dy^2}{dx^2} \right)$, but $dx^2 + dy^2 = dz^2$

hence $DP = (a+x) \cdot \dfrac{dz}{dx}$ Thus the equation $DA + DP = 2BP$

becomes $y - \dfrac{(a+x)dy}{dx} + \dfrac{(a+x)dz}{dx} = 2z$ which is the

equation of the curve required. ____

In order to find the integral let $p = \dfrac{dy}{dx}$, $q = \dfrac{dz}{dx}$

then the equation is $y + (a+x)(q - p) = 2z$ whence

$dy + (a+x)(dq - dp) + (q - p)dx = 2dz$ or by substituting

pdx, qdx for dy and dz, and reducing

$(a+x)(dq - dp) = qdx$ or, $\dfrac{dx}{a+x} = \dfrac{dq}{q} - \dfrac{dp}{q}$ and

taking the integral $\log(a+x) = \log q - \int \dfrac{dp}{q}$ but

since $q = \sqrt{1+p^2}$, $\int \dfrac{dp}{q} = \int \dfrac{dp}{\sqrt{1+p^2}} = \log\left(p + \sqrt{1+p^2}\right)$ hence

the integral of the equation becomes

Figure 8: The first page of Somerville's solution to Question 384, posed in Volume 4 of MR.

Somerville rearranged to get $p = \frac{a-x}{2\sqrt{ax}}$, and using this result and that $p = \frac{dy}{dx}$, integrated to show that

$$y = \sqrt{ax} - \frac{x^{\frac{3}{2}}}{3\sqrt{a}}. \tag{2}$$

The curve cuts the axis in two places, at $x = 0$ (by construction) and $x = 3a$, which Somerville labelled G (see Figure 8). Somerville proceeded to check that the curve she had found satisfied the criterion given by Wallace. She began by squaring and rearranging the equation of the curve, equation (2), to get

$$9ay^2 = x(3a-x)^2,$$

which she re-wrote as

$$9a : x :: (3a-x)^2 : y^2,$$

and then gave in terms of line segments as[43]

$$3BG : BQ :: QG^2 : PQ^2.$$

Somerville concluded her solution here, but we can see by rearranging and relabelling this expression that the curve does indeed satisfy equation (1);

$$3BC \times PQ^2 = BQ \times QC^2.$$

Notably, Somerville here used the notation and terminology often described by British mathematicians at the beginning of the nineteenth century as 'foreign' or 'continental'; she used dx rather than $\dot{x}$, and spoke of 'integrating' rather than 'taking the fluents'. This is especially significant when compared with the two solutions to this question actually published in MR. The first was given by 'Palaba', the proposer, and the second by William Wallace himself. Palaba's solution used similar triangles and fluxional calculus, whereas Wallace used differential notation, dx, dy, etc. However, Wallace's terminology did not match his notation; rather than 'differentiating' he 'takes the fluxions', and later he 'takes the fluents' when applying the inverse process. This seeming mismatch between notation and language is consistent throughout Wallace's other solutions in MR and is also witnessed in occasional solutions contributed by Messrs Lowry and Cunliffe, both professors at the Royal Military College

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43 The ratio notation here means the ratio of 3BG to BQ is equivalent to the ratio of QG^2 to PQ^2; or more succinctly $\frac{3BG}{BQ} = \frac{QG^2}{PQ^2}$.

with William and later John Wallace.[44] Other solutions which utilised the calculus in Volume 4 of MR utilised fluxional notation, such as $\dot{x}$, intermingled with the elongated s symbol of integration. Out of the 80 questions published in this volume, 27 had at least one solution which utilised calculus of some sort; of those solutions, 10 used purely differential notation and language. Seven of those were submitted by John Herschel, another founding member of the Analytical Society in Cambridge, one by William Wallace, and two were submissions by Mary Somerville. Therefore, considering the 'revolutionary spirit' with which differential notation was employed by those who wished to see the adoption of continental methods in British mathematics, Somerville was here both clearly identifying herself with the mathematical practice of this reform community, and contributing significantly to its visibility.

Beyond a mere commitment to differential notation, the two solutions belonging to Somerville which utilised the calculus and were printed in Volume 4 also demonstrate Somerville's expanding mathematical skill-set. Both solutions, to Questions 381 and 382 respectively, used trigonometrical functions and the differential calculus to investigate the properties of analytical curves; namely, curves described by a formula. An early solution to each question can be found in her notebook, and we proceed now to compare the published and unpublished solutions to Question 381, in order to display progress in Somerville's mathematical aptitude.

<div align="center">XI. QUESTION 381, <i>by</i> Palaba.</div>

The equation to the lemniscata being $(x^2 + y^2)^2 = x^2 - y^2$; find its area contained between the values of $x = 0$ and $= 1$[sic].

Both the published solution, which must have been submitted to the editors of MR before 1st August 1816, and the unpublished solution, being the fourth undated entry in the notebook, begin in the same manner (Leybourn, 1806–1835, 95, Vol 4). Somerville lets CPA be the lemniscata under consideration, where C is the 'centre', CA is the semi-axis,[45] and P is a point on the top right-hand side of the

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44 For example, William Wallace used fluxional language and differential notation in his solution to question 279 which "determine[d] the nature of the curve which touches an infinite number of lines of a given kind, described upon a plane according to some determinate law", and to question 358, which treated the sum of an infinite series (Leybourn, 1806–1835, 65, Vol 3), (Leybourn, 1806–1835, 54, Vol 4).

45 A minor difference between the two solutions, is that in the unpublished version Somerville takes a as the length of the semi-axis, rather than 1, which is carried through the solution; it is silently amended here for ease.
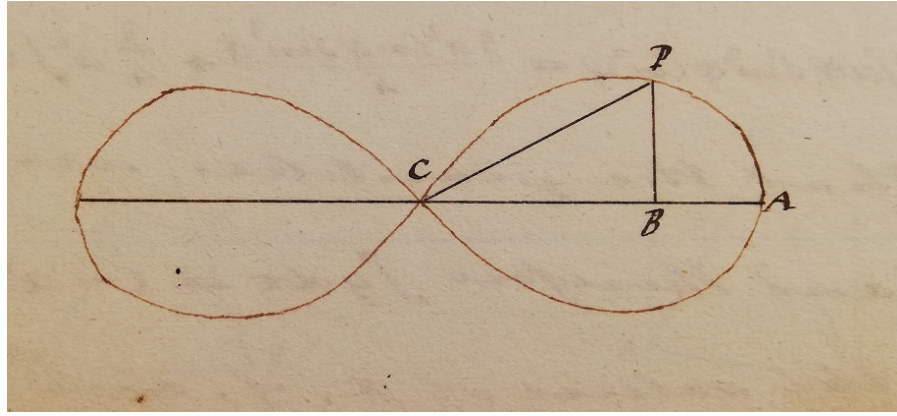
Figure 9: The diagram used by Somerville in her notebook answer to Question 381.

curve (see Figure 9). She then introduces the polar coordinates r and ϕ, where r is the 'variable radius' CP, and ϕ is the 'variable angle' PCA. Hence $x = r\cos\phi$ and $y = r\sin\phi$, and the equation to the curve becomes

$$r = \sqrt{\cos^2\phi - \sin^2\phi}.$$

Somerville then finds y and dx in terms of ϕ, and substitutes them into the 'general expression for areas', which she gives as $\int y\,dx$. This gives

$$\int y\,dx = \int d\phi \sin^4\phi - 3\int d\phi \sin^2\phi \cos^2\phi$$

and it is here that the solutions diverge.

First we consider the unpublished solution. Here Somerville computes the integration term by term, giving (with a missing three inserted into the left-hand side of the second line)

$$\int d\phi \sin^4\phi = -\frac{\cos\phi \sin^3\phi}{4} + \frac{3}{4}\int d\phi \sin^2\phi$$

and

$$3\int d\phi \sin^2\phi \cos^2\phi = \frac{3\cos\phi \sin^3\phi}{4} + \frac{3}{4}\int d\phi \sin^2\phi.$$

On subtracting the latter from the former, the terms under the integral sign cancel out, giving $\int y\,dx = c - \cos\phi \sin^3\phi$. Unfortunately, it is unclear how Somerville computed these integrals, as she has omitted all of her working. Somerville continues her solution by putting the equation for the area in terms of x and y,

$$\int y\,dx = c + \frac{xy^3}{y^2 - x^2},$$

and concludes by subtracting the value of this expression at $x = 1$ from its value at $x = 0$, to give the area as $\frac{y^3}{y^2-1}$.

This answer is clearly in the wrong form, as the solution should not be dependent on y; y is a function of x, and Somerville is integrating on an interval where the function is well defined, so the result of the integration should give a constant. However, perhaps because the function is given implicitly, and moreover is multivalued at the limits $x = 0$ and $x = 1$, Somerville was not able to evaluate the result when written in this form. This difficulty is overcome in the solution published in MR, as she instead gives the value of the integral in terms of the 'variable radius' r,

$$\text{area} = \int y\,dx = c - \frac{1}{4}(1 - r^2)\sqrt{1 - r^4}.$$

She then evaluates this expression at $r = 0$ ($x = 0$), and $r = 1$ ($x = 1$), and subtracts the latter from the former to give the area of one half oval as $\frac{1}{4}$ (and implicitly, by symmetry, the total area under the curve as equal to 1).[46] Therefore we see Somerville's fluency with trigonometric functions and polar coordinates increase between her first and second solution.

In addition, she demonstrated an improving fluency in methods of integration in her calculation of

$$\int y\,dx = \int d\phi \sin^4 \phi - 3 \int d\phi \sin^2 \phi \cos^2 \phi$$

in the published solution. Rather than computing the entire integral term by term, Somerville instead calculated

$$\int d\phi \sin^4 \phi = \int (d\phi \sin \phi) \sin^3 \phi = -\cos \phi \sin^3 \phi + 3 \int d\phi \cos^2 \phi \sin^2 \phi,$$

and noted that second term of the result cancels out the second term of the expression to be integrated. Her presentation of this integral strongly suggests that Somerville used the ubiquitous method now commonly known as Integration by Parts.

2.5 CONCLUSION

The knowledge of integration, trigonometric functions, and polar co-ordinates that Somerville cultivated through her correspondence with Wallace would have been vital for understanding Laplace's *Mécanique*

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46 For completeness, we note that the other solution to this question published in MR, which was submitted by the proposer 'Palaba', used fluxional calculus to reach the answer.

Céleste. Somerville claimed to have read this work between her two marriages, while living in Edinburgh, and recalled being stopped by difficulties 'now and then' (Somerville and Somerville, 1873, p. 81). Although she had John Playfair with whom to discuss her difficulties at that time, it is clear from her correspondence with Wallace that before 1816 she had very little practice in actually using the mathematics involved. In the first five years of her correspondence with William Wallace, during which she attempted questions set by him alongside those posed in MR itself, and reacted to his critical feedback, Somerville increased her mathematical fluency more than she had managed in the two decades since she first began studying Euclid by candlelight as a young girl. In 1817, just over a year after she submitted her final solution to MR, Somerville visited Laplace in Arcueil and had evidently progressed far enough in her reading of his work to make a very favourable impression (see section 3.2). Therefore the importance of Somerville's engagement with MR and her introduction to a *community* of mathematicians invested in circulating French analysis in Britain radically changed her level of engagement with mathematics, especially with the work that she would later become renowned for translating.

NAVIGATING GENDERED BARRIERS TO SCIENTIFIC KNOWLEDGE THROUGH SPOUSAL COOPERATION

Mary Somerville's life as a mathematician and 'savant' in nineteenth-century Great Britain was heavily influenced by her gender.[1] As a woman, her access to the ideas and resources developed and circulated in universities and scientific societies was highly restricted. However, her engagement with learned institutions was by no means non-existent, and although she was 90 before being elected a full member of any society (Società Geografica Italiana, 1870), she nevertheless benefited from the resources and social networks cultivated by such institutions from as early as 1812.

The mathematical landscape of Britain at the beginning of the nineteenth century was centred on a handful of public and private institutions: there were but six universities, with the University of Cambridge being the most highly regarded for mathematics; the Royal Military Academies; the Royal Observatory in Greenwich; and the Royal Society of London. These institutions played key roles in the cultivation of knowledge, providing spaces and resources for their members to both produce and circulate scientific knowledge. Hence membership or positions in these institutions (for example as Astronomer Royal, or as a student or tutor at a university) enabled and legitimised the work done by an individual. The legitimacy granted by an institutional position did not come from receiving a salary for scientific work, as very few did so and fewer still were reliant on these salaries in place of having private wealth (Chapman, 2015, p. 4). Rather the legitimacy stemmed from the demonstrated acceptance into an elite community of gentlemen.

As the century progressed these institutions increased in number and importance; new universities were founded, a second Royal Observatory was opened in Edinburgh, and there was a proliferation of learned societies. This proliferation is often attributed to disillusionment with the Royal Society of London, epitomized by Charles Babbage's infamous 1830 book, *Reflections on the Decline of Science in Eng-*

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1 This chapter uses significant material from an article published in *The Mathematical Intelligencer*, (Stenhouse, 2021), which appeared in French translation on the CNRS website *Images des Matheématiques* at https://tinyurl.com/cooperation-conjoints (accessed 11/05/2021).

land; new societies were founded whose members aimed to actively cultivate knowledge rather than act as expensive gentlemen's social clubs (Babbage, 1830, p. 50). Often founders felt that their subject of interest was being neglected by the Royal Society, and so founded a society with a more precise focus than just 'natural philosophy': the Linnean Society, which received its Royal Charter in 1802, provided a forum for those interested in taxonomy, biology and botany; the Geological Society was founded in 1807 by those who wanted to encourage research in geology; and the Royal Astronomical Society (RAS) was founded in 1820 by a group of gentleman to promote astronomy.[2] Whilst all of these societies were centred in London, there was a simultaneous movement to cultivate interest in scientific knowledge throughout Britain through the founding of local provincial societies, notably, the Literary and Philosophical Societies of Bristol and Newcastle respectively (Gleason, 1991). [3]

Knowledge was cultivated by these societies in a variety of ways. The Royal Society of Edinburgh was founded in 1783 with three specific objectives in mind: to provide a "personal and informal" social space for Fellows; to facilitate the publication of periodicals; and to assemble a library (Campbell, 1983, p. 8). Similarly, the founders of the Geological Society "met in consequence of a desire of communicating to each other the result of their observations ... [as] the remarks which are made by separate inquirers, however interesting in themselves, are less valuable from being unconnected" (Anon, 1811, pp. v–vi). The Geological Society began publishing their transactions in 1811, four years after the society's foundation, and by this time had already collected a significant mineral collection and library. Both societies recognised the huge importance of enabling scholars and natural philosophers to become socially acquainted.

The social bridges built between fellows and members of these societies were certainly not confined within their walls, nor were they by any means distinct between the different institutions. 'Men of science' or 'philosophers' (as they called themselves at the time) placed a much higher value on a broad scientific training, which they saw as the best way to inculcate contemporary ideals of masculinity (Ellis,

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2 The RAS was originally founded in 1820 as the Astronomical Society of London, changing their name in 1831 when they received a Royal Charter. For brevity I will refer to the society as the RAS throughout.

3 There was also a proliferation of provincial societies focused specifically on mathematics in the 18th century, such as the Spitalfields Mathematical Society founded in London in 1717, and societies in Manchester and Oldham. As yet, there is no evidence of Somerville engaging with these provincial mathematical societies, so they will not be discussed here.

2014, p. 6). Somerville herself wrote in the preface to her second book, *On the Connexion of the Physical Sciences*, that "there exists such a bond of union [between the physical sciences], that proficiency cannot be attained in any without a knowledge of others" (Somerville, 1834, preface). Social bridges were also not confined by state borders; the first president of the British Association for the Advancement of Science (BAAS), William Vernon Harcourt (1789-1871), claimed that the aim of the association was "to promote the intercourse of the cultivators of science with one another and with foreign philosophers", and most scientific societies elected 'Foreign' or 'Corresponding' members alongside full fellows (Harcourt, 1835, p. 22).[4] As we will see, many philosophers were involved with multiple societies, spanning a variety of disciplines, both within Great Britain and across Western Europe.

In contrast to this image of an open republic of knowledge, when considering women in science and mathematics, scientific societies and institutions usually play an exclusionary role. British women were ineligible for higher education until the founding of Bedford College, London in 1848, and to this day there has been no female Astronomer Royal (a prestigious post for a nineteenth-century mathematician). Although no scientific learned society had a formal statute barring women during Somerville's lifetime, there was nonetheless a great reticence to even allow women into the buildings, never mind to endow them with the rights of members. Except for the visit of the prolific author Margaret Cavendish in 1667, the Royal Society of London did not invite women into their hallowed halls until 1876, with the commencement of their second conversazione, which women were permitted to attend (Ferry, 2010, p. 163).[5] As late as 1886, on the nomination of Isis Pogson as a fellow, the Council of the Royal Astronomical Society chose to interpret their constitution as explicitly excluding women (Dreyer and Turner, 1923).[6] National societies which aimed to promote mathematics specifically were not founded until near the end of Somerville's life, namely the London Mathematical Society in

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4 As quoted in (Ellis, 2014, p. 787)

5 A 'conversazione' was an annual social gathering hosted by the Soirées Committee of the Royal Society, where experiments and objects of interest were displayed by and for fellows.

6 Women were first elected fellows of these societies in 1945 (Kathleen Lonsdale FRS and Marjory Stephenson FRS) and 1916 (Mary Adela Blagg FRAS, Ella Church FRAS, Alice Grace Cook FRAS, Irene Elizabeth Toye Warner FRAS, and Fiammetta Wilson FRAS) respectively. For more on the membership of women in learned societies in Britain see (Kidwell, 1984), (Mason, 1992), (Bailey, 2016).

1865 and the Société Mathématique de France in 1872, and again there was a significant delay before women were elected members.[7]

However, focusing too heavily on membership alone can distort our understanding of the influence which these institutions had, and furthermore lead to underestimating the role played by informal knowledge exchange through letter correspondence and polite sociability, which took place adjacent to the institutions themselves.[8] As Charles Babbage (1791–1871) noted in his aforementioned 1830 polemic against the Royal Society, only 109 out of 714 fellows had contributed a paper to the *Philosophical Transactions of the Royal Society* (*Philosophical Transactions*), while Caroline Herschel (1750–1848), who was never affiliated even as an honorary member, had been published three times describing her discoveries of new comets (Babbage, 1830, pp. 154–5).[9] For women, membership itself could be the least significant interaction with these institutions.[10]

Although her gender precluded her from attending university or holding full memberships of scientific academies relevant to her mathematical and scientific research, Somerville was awarded multiple *honorary* memberships. The earliest of these were in recognition of her first book, *Mechanism of the Heavens* (Somerville, 1831), (see Chapter 4). The Naval and Military Library and Museum of London was the first society to list Somerville as an honorary member, on 21st September 1832. This was followed in 1834 by election to la Société de Physique et d'Histoire Naturelle de Genève and the Royal Irish Academy, Dublin. Mary Somerville and Caroline Herschel were the first women to be elected Honorary Members of the Royal Astronomical Society (RAS) in February 1835, and later that year Somerville could add a certificate of honorary membership to the Bristol Philo-

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7 The first woman elected to the London Mathematical Society was Charlotte Scott in 1881, and Sophie Kovaleskaya was the first woman elected to the Société Mathématique de France in 1882.

8 Another demographic often excluded from memberships of scientific institutions were those of a low social status. The ways in which 'artisans' engaged with natural historical knowledge through corresponding with gentlemen is treated in (Secord, 1994).

9 The first two of these letter extracts — (Herschel, 1787), (Herschel, 1794) — were written to the Secretaries of the Royal Society at the time (Charles Blagden (1748–1820) and Joseph Planta (1744–1827) respectively), whilst the third was written to the President of the Royal Society, Joseph Banks (1743–1820) (Herschel, 1796). It is presumably these recipients who read the letters to the Royal Society. For more information on Caroline Herschel's engagement with the Royal Society see (Winterburn, 2018).

10 See (Jones, 2009, p. 178) for a table of women who published in the *Philosophical Transactions* between 1880 and 1914, before women were elected members of the Royal Society.

Figure 10: Marble bust of Mary Somerville by Francis Chantrey, Royal Society of London. Photograph by the author.

sophical and Literary Society to her collection (Somerville and Somerville, 1873, pp. 172–6).[11] Although never elected a Fellow of the Royal Society, in 1832 sixty-four fellows pledged £156.10 to commission a marble bust of Mary Somerville to be placed in the society's Meeting Room (see figure 10), in order to pay tribute to "the powers of the female mind, and at the same time establish an imperishable record of the perfect compatibility of the most exemplary discharge of the softer duties of domestic life, with the highest researches in mathematical philosophy" (Patterson, 1983, p. 90).[12]

These honorary memberships appear not to have benefited Somerville in any meaningful way. Payment of an admission fee and subsequent

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11 Certificates of memberships are held in MS, Dep. c. 375, along with further election certificates from later in her life. A few years earlier, in 1828, Caroline Herschel had been awarded the Gold Medal of the RAS.

12 MS, Dep. c. 375, MSDIP–2, John George Children (FRSec) to William Somerville 19/02/1832.

yearly subscription entitled members of the RAS to access the society meeting rooms and library, and to append the letters FRAS after their name (Babbage, 1830, p. 43). In the letter from Augustus De Morgan (1806–1871), Professor of Mathematics at University College London and Secretary of the RAS, where he informed Somerville of her election to honorary member, there is no suggestion that she was liable for this admission cost.[13] When in need of astronomy texts during the writing of an article on comets in 1835, rather than entering the library herself she chose to send a scientific colleague to consult the society collections on her behalf (Patterson, 1983, p. 167). Indeed although she wrote warmly in PR of the honour she felt in her honorary election to the RAS, when visiting the society in 1844 she claimed to be unaware that the election had even taken place![14] Whether this was because she had genuinely forgotten, or because she felt unable to assert her right to enter the building on the basis of her own membership, is impossible to say; nevertheless this clearly suggests she had not made free use of the space since her election in 1835. None of the other societies which bestowed honorary membership on Somerville were based in London (where she resided until 1838), so even had she wanted to attend meetings or make use of the facilities this would have been expensive and difficult. Similarly Somerville did not advertise her affiliations with learned societies by appending the appropriate letters to her name when signing her letters, or in the title pages of her publications where she appeared merely as 'Mrs Somerville' until 1835, and 'Mary Somerville' from then on.[15]

As we will see, thanks in large part to her husband and her active 'networking' in scientific society in Edinburgh, London, and Paris, long before her honorary memberships Somerville had already been successfully circumventing the barriers she faced.

3.1   THE SOMERVILLES AS A COLLABORATIVE COUPLE

In May 1812 Mary Greig married her first cousin Dr. William Somerville, beginning a long, happy marriage, which ended with William's death

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13 MS, Dep. c. 375, Folder MSDIP–3, Augustus De Morgan to Mary Somerville 13/02/1835

14 MS, Dep. c. 370, Folder MSD–3 123, Augustus De Morgan to Mary Somerville 08/09/1844.

15 The publications of Somerville's male scientific contemporaries often identified the many society affiliations of the author, for example (Babbage, 1822), (Herschel, 1826), (Playfair, 1812).

in 1860. In her *Personal Recollections* Somerville remembered William with the following words:

> The warmth with which Somerville entered into my success deeply affected me; for not one in ten thousand would have rejoiced at it as he did; but he was of a generous nature, far above jealousy, and he continued through life to take the kindest interest in all I did (Somerville and Somerville, 1873, p. 176).

Although this shows the fondness with which she remembered her second husband and hints towards the support she enjoyed, it is a huge understatement of the role William played in her scientific career. Far surpassing a mere 'kind interest', William's active mediation was vital to Somerville's access to knowledge and the overcoming of gendered barriers to scientific institutions on which her subsequent career as a scientific author was contingent.

Viewing the Somervilles as a collaborative couple adds a wholly new perspective to existing literature on 19th-century scientific couples. Whilst (Lykknes, Opitz, and Van Tiggelen, 2012) goes some way to deconstructing the pervasive husband-creator/wife-assistant narrative, nevertheless in the given case studies of heterosexual couples it was the man who was the more visible, productive, or respected member of the partnership, especially when regarding scientific labour as the primary focus.[16] The novelty of the Somervilles' relationship, especially William's disinterest in building his own scientific reputation, was recognised at the time by Charles Lyell who noted in a letter to his fiancée and fellow geologist Mary Horner that had "Mrs. Somerville been married to La Place, or some mathematician, we should never have heard of her work. She would have merged it in her husband's, and passed it off as his" (Lyell, 1881, p. 325). William certainly *was* interested in natural history and natural philosophy. When posted to South Africa as an army surgeon in the 1790s he wrote of his interactions with the local people, as well as descriptions of the local wildlife, and with Somerville amassed a large mineral collection throughout their lives, at one point accidentally giving her arsenic poisoning when analyzing one of their samples

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16 (Julian, 1996) looks at Kathleen and Thomas Londsdale as a collaborative scientific couple in which Kathleen is arguably more well known, but both partners appear to have pursued intellectual work independently of each other. Moreover the Lonsdales were working in the early 20th century when the scientific landscape looked vastly different, for example Kathleen was able to take advantage of a university education and paid positions as a researcher.

(Somerville and Somerville, 1873, p. 128).[17] Crucially for Somerville's own career and recognition, this never surpassed a general interest or gentlemanly pursuit.

The Somervilles were by no means the only so-called collaborative couple in their scientific and social network, which included not least the Murchisons, Bucklands, Katers, Marcets, Herschels and Smyths (many of whom we will meet in this chapter). (Opitz, Bergwik, and Van Tiggelen, 2016) has shown convincingly that the domestic sphere has always been critically important in the production of scientific knowledge, and this is easily seen in the Somervilles' milieu.[18] Intimacies were not developed between individuals alone, but between family units who were interconnected by marriage, university friendships, and scientific collaboration. Families often travelled together, whether for pleasure or on expeditions, they paid social calls together, and letter correspondence sharing both private and professional news was frequently written and received by multiple, if not all, members of a household. Whilst this chapter focuses on spousal cooperation, Somerville's children were also deeply interwoven into her scientific networks. Her only surviving son Woronzow Greig made numerous useful connections during his time at Trinity College, Cambridge — graduating in 1827, the year that Augustus De Morgan was placed as 4th Wrangler — before being elected a Fellow of the Royal Society in 1833. Her daughters Mary and Martha Somerville were close friends of Ada Lovelace and translated a German text for Charles Lyell during the preparation of the second volume of his *Principles of Geology* (Lyell, 1881, p. 313).

The Somervilles' married life began with a long journey from Edinburgh to Portsmouth, where William had been appointed deputy inspector of hospitals (Somerville and Somerville, 1873, p. 8). On the way they visited William Wallace, with whom Somerville had previously exchanged but one or two highly formal letters regarding solutions for the *Repository* (see section 2.3). Visiting Wallace in person allowed her to develop a much deeper intimacy with Wallace, which is witnessed in their later letters.

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17 An account of his 1801–2 expedition in Southern Africa was subsequently published as an appendix to (Barrow, 1806). William's own writing on the topic was published during his lifetime in (Daniell, 1820), and over 150 years later was republished with additional notes (and unfortunately a portrait of the seventeenth century poet William Somerville) in (Bradlow and Bradlow, 1979).

18 For a preliminary treatment of collaborative couples in mathematics specifically see (Kaufholz-Soldat and Oswald, 2020, pp. 113–118) and (Dunning and Stenhouse, 2021).

Figure 11: Oil on Canvas portrait of William Somerville. Somerville College,
          Oxford

In advance of their journey, John Playfair furnished the Somervilles with a letter of introduction to William Herschel (1738–1822), brother of Caroline Herschel and an astronomer well known for his discovery of the planet Uranus.[19]. Playfair described the Somervilles in his letter as

> ...two very intelligent and accomplished persons ; the Doctor has been very much over the world & has observed as well as seen a great deal of its surface and of the men that dwell upon it. Mrs Somerville is distinguished by knowledge of the Mathematical Sciences rarely to be met with in men. She has studied Geometry and algebra with great success, & is particularly well acquainted with astronomy.[20]

William Wallace also contacted Herschel on the Somervilles' behalf, asking permission to pay a call accompanied by the visiting couple; Herschel replied that he would be "very happy to see the Lady... and you may be assured that the trait in the character of a Lady to be a good mathematician without Wrangleship[sic] will be highly esteemed".[21] Somerville fondly recalled the visit in PR, when she was shown Herschel's telescopes as well as manuscripts of his astronomical observations, and first met John Herschel (son of William and Mary Pitt Herschel), with whom she shared a lifelong friendship and who, as we will see, played a key role in her mathematical career.[22]

As well as introducing Somerville to the Herschels, it is very likely that it was at this time that Wallace assisted Somerville in the assembly of her own personal mathematical library (see section 2.3), offering advice on which texts she should purchase and gifting her his own copy of Joseph Louis Lagrange's *Théorie des fonctions analytiques...* (Lagrange, 1797). Owing to her own limited financial resources and limited access to the libraries of scientific institutions,

19 Travellers were highly dependent on acquiring letters of introduction to people of note (or those who could be of help) who resided in their intended destination, for example British Ministers or "respectable foreigners" (Meyer, 1978, p. 48)

20 Royal Society, Herschel Papers, HS 14.169, 16/06/1812.

21 MS, Dep. c. 370, Folder MSH–4, 8/07/1812. "Wranglership" here refers to the title of 'Wrangler' which was given to those in the first class in the Senate House examination, or Mathematical Tripos at Cambridge University (Craik, 2007, p. 3).

22 Somerville claimed in PR that Caroline Herschel was abroad at the time of this visit, and makes no mention of having met her on a subsequent occasion (Somerville and Somerville, 1873, p. 106). Caroline Herschel's memoir suggests the two women were aware of each other's astronomical work, and in 1835 Somerville wrote to Herschel on the occasion of them being simultaneously elected the first women to be honorary members of the RAS, and offered a copy of her second book *On the Connexion of the Physical Sciences* (Somerville, 1835b) (Herschel, 1876, p. 274).

this informal exchange of knowledge through gifting and lending of books was invaluable to Somerville, and continued throughout her life (see section 5.4).

The Somervilles soon returned to live in Edinburgh when William was hired as head of the Army Medical Department in North Britain (Somerville and Somerville, 1873, p. 8). In January 1813, William was elected an Ordinary Member of the Royal Society of Edinburgh (RSE), having been proposed by John Playfair (Anon, 1815, p. 542), (Waterston and Shearer, 2006, p. 869); during the same election zoologist Georges Cuvier (1769-1832) and mathematician Pierre-Simon Laplace were elected as Honorary Members, both of whom the Somervilles would later meet in Paris in 1817. The RSE had long fostered mathematics, as evidenced by Playfair's paper on the applications of analytical methods to mechanics published in the society's *Transactions* as early as 1788 (Playfair, 1788).[23]

Three years after William's election, just before moving to London on his appointment as a Principal Inspector of the Army Medical Board, the Somervilles became acquainted with Leonard Horner (1785-1864), an active member of the London Geological Society.[24] Horner was elected a Fellow of the RSE in 1816, so it is very possible that he met the Somervilles through this mutual association. He played a key role in the Somervilles' new life in London through writing a letter of introduction to the physician Alexander Marcet (1770-1822). In his letter, Horner described William Somerville as "a very good fellow, & his wife a very interesting woman. She is a person of extraordinary acquirements, particularly in mathematics. But she has not a shade of blue in her stockings" (Patterson, 1983, p. 12).[25] Horner furthermore asked that Jane Marcet (1769-1858), author of the highly successful book *Conversations on Chemistry* and wife of Alexander, pay a call to the Somervilles on their arrival in London. Jane Marcet did so, and the two scientific women became lifelong friends.

The Marcets introduced the Somervilles into a thriving metropolitan community which included fellows of the Royal Society, the Linnean Society, and the Geological Society; all three of which William

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23 In the early nineteenth century, Wallace and Ivory also published papers on the calculus of fluxions in the *Transactions* of the RSE (Guicciardini, 1989, p. 98).

24 Leonard Horner was the father of the aforementioned geologist Mary Horner and, as another indication of the many social ties between members of Somerville's scientific circle, Horner and her future husband Charles Lyell apparently first met in Somerville's house (Somerville and Somerville, 1873, p. 145).

25 Originating from the eighteenth-century Bluestockings Society led by Elizabeth Montagu, in the nineteenth century 'bluestocking' became a derogatory term for a woman interested only in intellectual pursuits (Griffin, 2017).

Somerville himself became a fellow or member of by 1817. Alexander Marcet was one of seventeen signatories on William's certificate of election to the Royal Society alongside John Herschel, Astronomer Royal John Pond (1767-1836), as well as chemists and future Presidents of the Society, Sir Humphry Davy (1778-1829) and William Hyde Wollaston (1766-1828).[26].

We highlight here that William's election certificate listed his *acquirements* in natural history and mineralogy as sufficient for membership of the Royal Society; but what of Somerville's acquirements? As was shown in Chapter 2, by 1817 two of her puzzle solutions had been published in *The New Series of the Mathematical Repository*, and her aptitude in mathematics was recognised by Playfair, Wallace, and Horner in the letters quoted above. Somerville's reputation for excellence became so widely known that in 1822 novelist Maria Edgeworth (1768–1849) described her as "the lady whom La Place mentions as the only woman in England who understands his works".[27] Furthermore, alongside knowledge of Natural Philosophy more broadly or employment in universities, being 'conversant' in mathematics was used as justification for the election of 25 new fellows of the Royal Society during this time of Somerville's increasing renown, and in 1823 Lewis Evans was elected purely for being "a Gentleman well skilled in Mathematics and Astronomy".[28] Therefore, the absence of Somerville's nomination, to the Royal Society at least, was clearly an issue of gender.

Nevertheless, Somerville was by no means isolated from scientific societies, as she was able to engage in the sociability surrounding and connecting these closed institutions, which was a key component of scientific and mathematical activity. Moreover, William actively shared the benefits of his memberships; as a member of multiple societies, as well as gentlemen's clubs such as the Athenaeum and exclusive dining clubs including the Pow-Wow Club, he was well placed to meet the brightest stars in British science (Patterson, 1983, p. 32). Depending on the situation, William took on the roles of Somerville's chaperone, secretary, representative, or even literary agent. We will investigate each of these in turn, to illuminate the types and ways in which Somerville's engagement in mathematical

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26 RS EC/1817/14. At the time, election certificates of candidates were displayed at ten ordinary meetings of the society, and required the signatures of three or more members to be successful (Crosland, 1983, p. 168).

27 Maria Edgeworth to Miss Ruxton 17/01/1822, reproduced in (Somerville and Somerville, 1873, p. 156).

28 Election certificates were viewed at royalsociety.org/collections on 06/05/2020.

and scientific communities was affected and improved through her husband's assistance.

3.2 CHAPERONE

On her marriage to William, Somerville's social and geographical mobility was transformed, as, with a husband who shared her scientific interests and enjoyment of polite company, she now had a constant companion and eager chaperone. That Somerville was much more socially mobile as a married woman, whether or not she was always accompanied by William, is clear to see from the great increase in her visibility within scientific society from 1812 onwards.

Although British women from the middle and upper classes had been global travellers since at least the early 18th century, it was very rare for a woman to travel alone.[29] Very often women travelled with their spouse as a companion, or as a collaborator taking an active part in observation and collecting, depending on the purpose of the travel; without a family member to act as chaperone, women were otherwise dependent on finding paid servants or local guides willing to accompany them on their travels (Meyer, 1978, p. 29).[30] Travel costs were prohibitive enough to the Somervilles even without the added cost of paying for a maid to act as a companion and provide childcare on the go, and in 1832 Somerville lamented that she was forced to be "stationary all summer [as] moving is so expensive" (Patterson, 1983, p. 94).[31]

The importance of a chaperone is underlined in Somerville's letters from Francis Jeffrey (1773–1850), editor of the *Edinburgh Review*, in which he implored her to attend the 1834 annual meeting of the British Association for the Advancement of Science (BAAS), taking place in Edinburgh. He expressed his great disappointment that Some-

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29 One such traveller was Jane, Lady Franklin who travelled extensively with her niece Sophia Cracroft. Franklin visited Somerville in Spezia where she assured her "that although they went to Japan and China they never experienced any difficulty. Seeing ladies travelling alone, people were always willing to help them" (Somerville and Somerville, 1873, p. 137). For more on Franklin, see (Alexander, 2013).

30 Meyer gives no insight as to how, or if, female servants hired as companions for one-way journeys made it back home.

31 Travelling with children was not unusual at the time. In 1817 the Somervilles took their 4 year old daughter on their tour of the continent, but left their two sons in the care of relatives in Scotland and their two infant daughters with William's sister (Patterson, 1983, pp. 17–19); seven years later when travelling to the Low Countries Woronzow Greig, then 19 years old, accompanied them, but their two young daughters were left in the care of a governess (their eldest daughter having recently died) (Patterson, 1983, pp. 44–45).

rville was not intending to travel north for the meeting, both for the personal loss of her good company, but also that the first Scottish meeting of the BAAS would be deprived of the honour of her attendance. Jeffrey acknowledged the inconvenience to William to be so far from London at that time as the reason for Somerville's intended absence, and asked

> if the inconvenience is insurmountable should not you come without him? If I were in your neighbourhood I should whisper this in your private ear, in the most seductive terms... the Dr did allow you to stay Heaven knows how many months in the profligate Paris without him. I cannot but hope that he may consent your being as many weeks in our moral Edinburgh.[32]

That Jeffrey should feel the need to convince Somerville to travel without her spouse in a 'private seductive whisper' strongly suggests that he was aware it would be a decision that could not be made lightly. Moreover, his recourse to the moral standing of Edinburgh makes clear that the difficulties and dangers lay not just in the travel itself — the journey from London to Edinburgh would have taken around 10 days by coach — but also in attending society and BAAS gatherings whilst unchaperoned in the city.[33]

Although she still had no publications to her name, by 1817 Somerville's reputation as a mathematician began to spread through Edinburgh, London, and beyond. The ease with which she managed to build a reputation for herself is partly owing to the importance in intellectual circles of the "soirée, conversazione, dinner-party, and other informal sociable gatherings", spaces in which Somerville seems to have been at ease (Chapman, 2015, p. 25). Via the Marcets, Somerville became acquainted with the French men of science Joseph-Louis Gay-Lussac, François Arago and Jean-Baptiste Biot, while they were were visiting Britain in 1816–7 for their research. Biot, who was a member of the mathematics section of the Institut de France and a professor of astronomy at the Faculté des sciences in Paris, was clearly aware of and impressed by her studies, as in a letter written to William in June of 1817 he begs her to contact him with any difficulty she may

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32 MS, Dep. c. 371, MSJ–1 20, Francis Jeffrey to Mary Somerville 13/08/1834. For more information on the BAAS, see (Morrell and Thackray, 1981) and (Ellis, 2017).

33 Unfortunately a treatment of the real and perceived dangers for women travelling or navigating society without a suitable chaperone in the 19th century is beyond the scope of this thesis.

meet in mathematics.[34] Four weeks later Biot wrote to Somerville directly, entreating her to visit him in Paris, where he promised a warm welcome from both him and his wife, and persons who already had a great desire to make her acquaintance.[35]

With the accompaniment of her husband and brother, on 17th July 1817 she began the five day journey to Paris, where they were to stay for two weeks en route to Geneva and Rome. Having already met Biot and Arago in London, on arriving in Paris the Somervilles gained easy access to the most prestigious learned institutions, and became acquainted with many of the most well known philosophers of the day. During her two weeks in the city, Somerville kept a diary where she detailed hearing papers read at the Institut de France, visiting astronomer Claude Louis Mathieu (1783–1875) at the Paris Observatory, and receiving "the greatest attention" from Gabrielle Biot (1781–1851), a scientific translator and wife of Jean-Baptiste. Biot organised a dinner in order to introduce Somerville to "les personnes distinguees[sic]", including mathematician Simeon-Denis Poisson (1781–1840) and geographer Alexander von Humboldt (1769–1859).[36] Somerville knew of Gabrielle Biot's mathematical translation of Ernst Gottfried Fischer's *Lehrbuch der Mechanischen Naturlehre*, writing in her diary:

> It is by no means a fair thing to give an opinion of any set of people on a short acquaintance, Yet I could not avoid being struck by the difference between the accomplishments of the French and English ladies, among all I have met with only one who pretended to know a little music and that was poor indeed, two drew a little, language and science I met with none except in Mme Biot and she had made a translation from the German of a work which

34 "Je l'ai priée, si elle rencontrait quelques difficultés dans les études mathématiques de vouloir bien me les envoyer et je ne lui ferai pas attendre la réponse", MSC, Dep. c. 369, Folder MSB–8, 01/06/1817.

35 "Pour vous madame vous allez à Paris ; et vous y trouverez je vous assure des personnes qui ont déjà une très grande envie de vous voir", MSC, Dep. c. 369, Folder MSB–8, 27/06/1817, as referenced in (Patterson, 1983, p. 17).

36 MS, Dep. c. 355, MSAU–1. Somerville's diary covering her time in Paris is reproduced in (Patterson, 1985). When Humphry Davy travelled to Paris four years earlier, notably still during the reign of Napoleon, he visited many of the same institutions as Somerville, including the Jardin des Plantes and the Institut de France. It appears that women were welcome to attend meetings of the Académie des Inscriptions et Belles-Lettres at the Institut de France as spectators, as Somerville did so in the company of Gabrielle Biot. This was a somewhat less triumphant welcome than that of Davy who was seated at the right hand of the President of the First Class of the Institut, and whose presence was officially announced to the meeting (Paris, 1831, p. 14).

is published under the name of her husband. Certainly I found none of the high cultivations of mind and elegance of manners so constantly seen in England, not among the higher classes alone but widely diffused throughout the nation.[37]

Near the end of their visit the Somervilles were hosted by Pierre-Simon Laplace at Arcueil; that Somerville was able to meet and impress the mathematician whose work she was so well known for having studied, when few others in Britain were capable of doing so, was invaluable both to her intellectual pursuits and reputation.[38] Although Somerville had previously benefited from discussions on Laplace's *Mécanique Céleste* with John Playfair, Playfair himself admitted to his own limited understanding of the advanced mathematics it contained (Playfair, 1808, p. 275). At dinner in Arcueil, Somerville conversed with Laplace on his scientific works, including potential improvements in analytical methods regarding the convergence of series (Patterson, 1985, p. 360). Seven years later he wrote to Somerville claiming that "the interest which you deign to take in my work flatters me all the more as there are few other readers and judges so enlightened" (Hahn, 2013, pp. 1250–1).[39] This is especially pertinent when according to Somerville, Laplace's initial response to being told that she had read his work was to doubt that the English or any other nation could appreciate the beauties of French literature![40] With his letter in 1824, Laplace enclosed a copy of the fifth edition of his *Système du Monde* for Somerville to add to her personal collection of mathematical texts, giving her the freedom to consult it at her leisure (Laplace, 1824).[41] Such an endorsement from Laplace compounded Somerville's reputation as an expert mathematician, and the story of Laplace describing Somerville as the only person in Britain who understood his work is echoed throughout contemporary accounts of her life, appearing in the description given by Edgeworth above, in the diary of Queen Victoria in 1838, and even in a Nevada Newspaper in the USA in 1873 (Anon, 1873).[42]

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37 MS, Dep. b. 207, MSAU-1.

38 Laplace's country estate in Arcueil was home to "the most important private scientific society of the age", the Society of Arcueil, of which, out of Somerville's acquaintance, Biot, Arago, Poisson and Gay-Lussac were members (Crosland, 1967).

39 "L'intérêt que vous [Somerville] daignez prendre à mes ouvrages me flatte d'autant plus, qu'ils ont bien peu de semblables lecteurs et de juges aussi éclairés".

40 MSC, Dep. c. 355, Folder MSAU–1, 06/08/1817.

41 This copy of Laplace's *Système du Monde* is held in the Girton College Library: Somerville Collection (073196).

42 Queen Victoria's diary entry is from Sunday 30th December 1838, Lord Esher's typescripts, viewed online at www.queenvictoriasjournals.org on 22/05/2020. The entry

After leaving Paris, when the diary tails off, the Somervilles continued on to Geneva, before spending the winter and spring in multiple cities across the Italian peninsula and returning to London in late summer of 1818.[43] Somerville returned to continental Europe in 1824 when, along with her husband and eldest son from her first marriage, she visited what is now Belgium, the Netherlands and Germany. In Brussels she became acquainted with astronomer Adolphe Quetelet (1796–1874), who would later publish translations and reviews of Somerville's work in the *Correspondance Mathématique et Physique*, of which he was editor; in Bonn the Somervilles renewed their acquaintance with Alexander von Humboldt; and whilst in Utrecht Somerville met astronomer Gerard Moll (1785—1838) (Patterson, 1983, p. 45).[44]

Beyond an increased geographical mobility, Somerville's marriage to William also increased her mobility within scientific society itself. On moving to London in 1816, the Somervilles took up residence at Hanover Square in London's fashionable west end, where they were well positioned to engage in the social calls and occasions that made up London society. In her *Personal Recollections*, Somerville recounts numerous instances of engaging in informal experiments or taking of observations in the homes and gardens of her friends. One such anecdote entails testing the power of a telescope by making observations of double stars — a pair of stars that appear close together, and often require a powerful telescope to make them out individually — with Henry (1777–1835) and Mary Frances Kater (1784–1833) until the early hours of the morning. On their way home, the Somervilles noticed a light in the window of Thomas Young (1773–1829), author of an anonymous partial translation of *Mécanique Céleste* and whose name is nowadays associated with the modulus of elasticity (Young and Laplace, 1821). On ringing his bell they were invited inside to see an Egyptian papyrus which Young had just identified as a horoscope (Somerville and Somerville, 1873, pp. 130–131). The dates and details of such stories as given by Somerville are often unreliable, but the impression remains (and is borne out in her correspondence) that she

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names La Grange rather than La Place, but Lagrange died in 1813, four years before Somerville visited Paris.

43 Although they appear to have made a good impression on society whilst travelling through Italy, there is no evidence of Somerville actively pursuing her mathematical interests nor making the acquaintance of others who could be named as 'mathematicians' (Patterson, 1983, pp. 26–30).

44 Moll would later author an anonymous rebuttal to Charles Babbage's 1830 polemic *Reflections on the Decline of Science in England* (Babbage, 1830), (Moll, 1831), (Reingold, 1968).

was able to enjoy close personal connections as well as intellectual exchanges through her lively social life.

Whilst there is little evidence of how Somerville was able to cultivate social connections with such a vast array of notable scientists and luminaries, it is likely that the Somervilles' participation in scientific societies and institutions played a key role. Hanover Square was within walking distance of the Royal Institution (RI) on Albemarle Street which, soon after its founding in 1799, had been absorbed into the London social season with 'subscribers' attending lectures in the same way that they would attend the opera or theatre (Somerville and Somerville, 1873, p. 107), (Lloyd, 2019, p. 113). Women were eligible for all levels of membership of the RI,[45] and indeed between 1800–1812 women often outnumbered men in the audiences of lectures, which covered scientific topics such as mechanics, chemistry, and botany, as well as painting, architecture and poetry (Lloyd, 2019, pp. 123–4). Whilst we know a little bit about William's engagement with the RI, namely that he was listed as an annual subscriber in 1816 and later named on the 'List of Managers of the Royal Institution' (Patterson, 1983, pp. 11, 91), less is known about Somerville's. As previously noted, Somerville subscribed to the RI while living in London with her first husband; her name is again recorded as a subscriber to the lectures in 1825.[46] In addition, in her *Personal Recollections* she mentioned attending the lectures, frequently with William, on her return from travelling Europe in 1818 (Somerville and Somerville, 1873, p. 107). Over half a century later, Somerville was informed by William Spottiswoode (1825–1883) that by agreement of the members, the proceedings of the Royal Institution would be sent to Somerville in Naples as and when they appeared.[47]

In 1832 it was William who liaised with Plumian Professor of Astronomy, George Biddell Airy, and Woodwardian Professor of Geology, Adam Sedgwick, to organise a week-long visit to Cambridge. The novelty of Mary Somerville's visit to the male-domain of Cambridge University is underlined by the difficulties faced of finding a

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45 There were six types of subscriptions available, including an annual subscription only offered to 'Ladies' which allowed access to the lectures and mineralogical collections, but not the library and model room (Lloyd, 2019, p. 59).

46 'Mrs Somerville of Hanover Square', Royal Institution Managers Minutes, 7 March 1825, volume 7, p.11. I am extremely grateful to Frank James for providing this information and reference during the archive closures caused by Covid-19.

47 NLS, MS 41131, 197, Mary Somerville to John Murray III, 4/03/1870. Although this privilege had been offered to Somerville, she felt it to be indelicate to write directly to the managers of the RI when she stopped receiving the proceedings, and asked Murray to intervene on her behalf. This again shows that the granting of such privileges doesn't always equate to equal access.

suitable sleeping arrangement; eventually Sedgwick arranged for the Somervilles to stay in the rooms of Trinity Fellow and astronomer Richard Sheepshanks (1794—1855), and wrote to Dr Somerville that "a four poster bed (a thing utterly out of our regular monastic system) will be had" for their visit (Clark and Hughes, 1890, pp. 387–390).[48] Whilst in Cambridge Somerville met with George Peacock and William Whewell (1794–1866), a former member of the Analytical Society and later Master of Trinity College, Cambridge, both of whom heavily influenced the mathematical tripos in Cambridge. The visit was packed full of social engagements to such an extent that afterwards William Rowan Hamilton, an Irish mathematician whose acquaintance Somerville made during her stay, wrote of the week:

> we lived in a continual round of engagements, and found Cambridge so gay, that Airy, who hates ladies' parties, complains that we shall have gone away with quite a false and unjust notion of the University. (Graves, 1882, p. 553).

Having published her first book *Mechanism of the Heavens* a few months earlier, it is clear that Somerville was received in Cambridge as an intellectual equal, or indeed an intellectual superior. Sedgwick apologised that owing to a lack of cannons there would be no gun salute on her arrival(!), and arranged for a small mathematical library to be at her disposal throughout the week in case she "tired of duller subjects" (Clark and Hughes, 1890, p. 387). Whewell subsequently described Somerville as "one of the best mathematicians in England" when writing of her visit, but that she nevertheless possessed the usual accomplishments of ladies, including music, drawing, and languages (Douglas, 1881, p. 142).

Somerville herself later acted as chaperone to a young Ada Byron (1815–1852), later Ada King, Countess of Lovelace. As a child, Lovelace had received tuition in mathematics from her mother, as well as informal guidance from Dr William King who suggested books for her to read and answered her mathematical queries via letter (Hollings, Martin, and Rice, 2017b, p. 227).[49] In late 1839 Lovelace began searching for a mathematics tutor, but it was almost a year later that she informed her mother a tutor had been found, and she re-commenced her mathematical studies under the tutelage of Augustus De Morgan (Hollings, Martin, and Rice, 2017a, p. 205). Three years

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48 MS, Dep. c. 369, MSA–1 210, 30/03/1832 and MS Dep. c. 372, MSS–4 49–51, 03–04/1832.

49 I will refer to Ada King as Lovelace throughout, as that is the name by which she is most commonly known. Dr William King (1786–1865) was a physician, and no relation of William King (1805–1893) who Lovelace married on 8th July 1835.

later Lovelace's translation of Luigi Menebrea's *Notions sur la Machine Analytique de M. Charles Babbage* was published; this paper, which contained extensive appendices, is the work for which Lovelace is best remembered today (Lovelace, 1843).

Somerville and Lovelace became acquainted in the early 1830s when the latter was still a teenager. That Somerville acted as a sort of informal mathematical and scientific guide to Lovelace is evidenced in their letters, for example in 1835 when Lovelace asked for help with an exercise on the compound angle formulae for sine and cosine (Hollings, Martin, and Rice, 2017b, p. 230). A year later Somerville made enquiries on Lovelace's behalf to procure a set of solid models which would illustrate propositions in spherical geometry, relating to the intersections of great circles. The models were eventually sourced via Scottish physicist William Ritchie (c.1790–1837), at this time Professor of Natural Philosophy at the Royal Institution. For reasons not given, Lovelace wished to remain anonymous as the purchaser of the models, so the enquiry and the transaction were all carried out by Somerville and indeed the models were delivered to Somerville's house.[50] That Lovelace trusted Somerville to make the enquiries not only demonstrates their intimacy, but also that Somerville was clearly well connected and respected in scientific circles; it was expected that she would know who to contact to commission the models and moreover that her name on the letter would command a positive response.

Whilst living in London and not yet married, Lovelace somewhat hesitantly turned to Somerville when she was in need of accompaniment to one of Babbage's Saturday soirées where the great names of London science gathered: "If you are going to Babbage's tonight, will you do me so great a favour as to call for me at 10, Wimpole St, & take me there. I am in a loss for a chaperone, or should not have taken such a liberty."[51] Somerville chaperoned Lovelace at least twice more to these Saturdays at Babbages, as witnessed in their correspondence.[52] It is likely that the frequency which Somerville chaperoned Lovelace in society was in fact much greater, as when visiting London in 1835 American linguist George Ticknor (1791–1871) observed in his journal that Lady Byron never went out in to society, and that whenever her daughter Ada did so, she was accompanied by 'Mrs. Somerville' (Hillard, 1880, pp. 410–411). That Lovelace was near in age to Somerville's two daughters, and shared their interests in music

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50 MS, Dep. c. 367, MSBY–3 70 & 71 & 74, Ada Lovelace to Mary Somerville. I am grateful to Christopher Hollings for bringing the letter exchange on the models to my attention.

51 MS, Dep. c. 367, MSBY–2 30, undated (but signed A A Byron).

52 MS, Dep. c. 367, MSBY–2 33 undated, & 45 26/11/1834.

and languages, certainly strengthened the intimacy between the two families, who visited each other often (Seymour, 2020). Lovelace's future husband, Lord William King, was a close friend of Woronzow Greig, and together they had gone on their Grand Tour in 1827 (Patterson, 1983, p. 150). After her marriage and move to Ockham Park House in Surrey, Lovelace often invited Somerville's daughters to stay with her, at one time assuring Somerville that she would "take great care of them, & be a vigilant chaperon[sic], informing you as soon as either of them has eloped & is beyond reach".[53]

3.3 REPRESENTATIVE AND ADVOCATE

Nonetheless, even with such an able and willing chaperone in her husband, there were doors which remained closed for Somerville. In an undated letter from mathematician Charles Babbage, Babbage gave the details of a dinner at which both William and Somerville were expected, and then the time and location of the inaugural meeting of the Statistical Society.[54] Babbage was one of the co-founders of the Statistical Society, alongside Woronzow Greig who was elected one of the three inaugural society secretaries (Mouat, 1885). Babbage and Somerville were well acquainted by 1834, and had shared a distinctly mathematical discourse. Within their extant correspondence we see Somerville invited to Babbage's house to view his 'calculating machine', Babbage offering advice during the preparation of *Mechanism of the Heavens*, and multiple letters mention the sharing of mathematical papers, such as John Herschel and Augustus De Morgan's articles in the *Encyclopedia Metropolitana*. Babbage also seems to have shared offprints of his own papers with Somerville, as manuscripts of five such papers are held in the Mary Somerville Collection at the Bodleian (see figure 12).[55] Meanwhile the correspondence between Babbage and William focuses for the most part on social engagements. Yet, it was only to William that the invitation to the inaugural meeting of the Statistical Society was extended. Even with her supportive hus-

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53 MS, Dep. c. 367 MSBY–3 66, Ada Lovelace to Mary Somerville 10/02/1836.

54 MS, Dep. c. 369, MSB–1 265, Charles Babbage to William Somerville (undated).

55 MS, Dep. c. 369, MSB–1 230 & 238. Babbage's papers are: 'An Essay Towards the Calculus of Functions', *Philosophical Transactions*, Charles Babbage, June 1815; 'An Essay Towards the Calculus of Functions Part 2', *Philosophical Transactions*, Charles Babbage, March 1816; 'Observations on the Analogy Which Subsists between the Calculus of Functions and other branches of analysis', *Philosophical Transactions*, Charles Babbage, April 1817; 'Observations on the Notation Employed in the Calculus of Functions', *Transactions of the Cambridge Philosophical Society*, Charles Babbage, May 1820; 'On the Influence of Signs in Mathematical Reasoning', *Transactions of the Cambridge Philosophical Society*, Charles Babbage, Dec 1821, held in MS, Dep. c. 369, MSB–16.

band, son, and friend as founding members, as a woman Somerville's presence was not desired at a society meeting.

Therefore, within the physical spaces of the scientific societies, William was required to act as Somerville's representative and advocate. One of the most visible and significant instances of this was in February 1826, when William communicated Somerville's paper 'On the magnetizing power of the more refrangible solar rays' to the Royal Society. When subsequently printed in the *Philosophical Transactions* the heading notes that the paper was 'communicated by W. Somerville M.D.F.R.S.', but authorship is clearly attributed to 'Mrs. M. Somerville' (Somerville, 1826).[56] This paper was Somerville's first publication under her own name — rather than a pseudonym — and she became only the second woman to be so published in the *Philosophical Transactions* of the Royal Society, after Caroline Herschel. No papers written by William himself were ever published in the journal, and Somerville's only other paper was an extract of a letter she had written to John Herschel which he communicated to the Royal Society on her behalf.[57]

In an editorial note in PR, Martha Somerville described how William would visit libraries of the learned societies on Somerville's behalf to source books she required (Somerville and Somerville, 1873, p. 84).[58] This is corroborated in the lending records of the Royal Society, in which his name appears 15 times between 1825 and 1840: in 1828 he took out two volumes of Roger Long's *Astronomy, in five books* (Long, 1742); in 1832 he borrowed Poisson's *Nouvelle Théorie de l'Action Capillaire*, Biot's *Précis élémentaire de physique expérimentale*, and volume 106 of the *Philosophical Transactions* which contained mathematical papers by both Babbage and John Herschel from their time in the Analytical Society; entries in 1834 include Volume 9 of the *Philosophical Magazine* and Volume 3 of the *Memoires d'Arcueil*; and finally in 1837 William borrowed Volumes 1 to 13 of the *Comptes Rendus*. During 1832, 1834 and 1837 Somerville was in the process of preparing successive edi-

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56 The experiment detailed in this paper involved exposing a steel sewing needle to violet light and Somerville concluded that this produced a permanent magnetising effect on the needle. During her lifetime the results of her experiment were contested, and she wrote in the first draft of her autobiography that she was "heartily ashamed" of having published the paper in the *Philosophical Transactions* as she feared her results were incorrect (Patterson, 1983, p. 48). In 2001 Sarah Parkin, a research student at the University of Oxford attempted to recreate the experiment (Parkin, 2001), (Chapman, 2015, p. 45).

57 See letters in RS: MC.4.92, HS 5.269, HS 16.352, & HS 16.353.

58 In a nice inversion of women acting as transcribers for their husbands or collaborators, Martha also describes William "indefatigably copying and re-copying her [Somerville's] manuscripts to save her time" (Somerville and Somerville, 1873, p. 84).
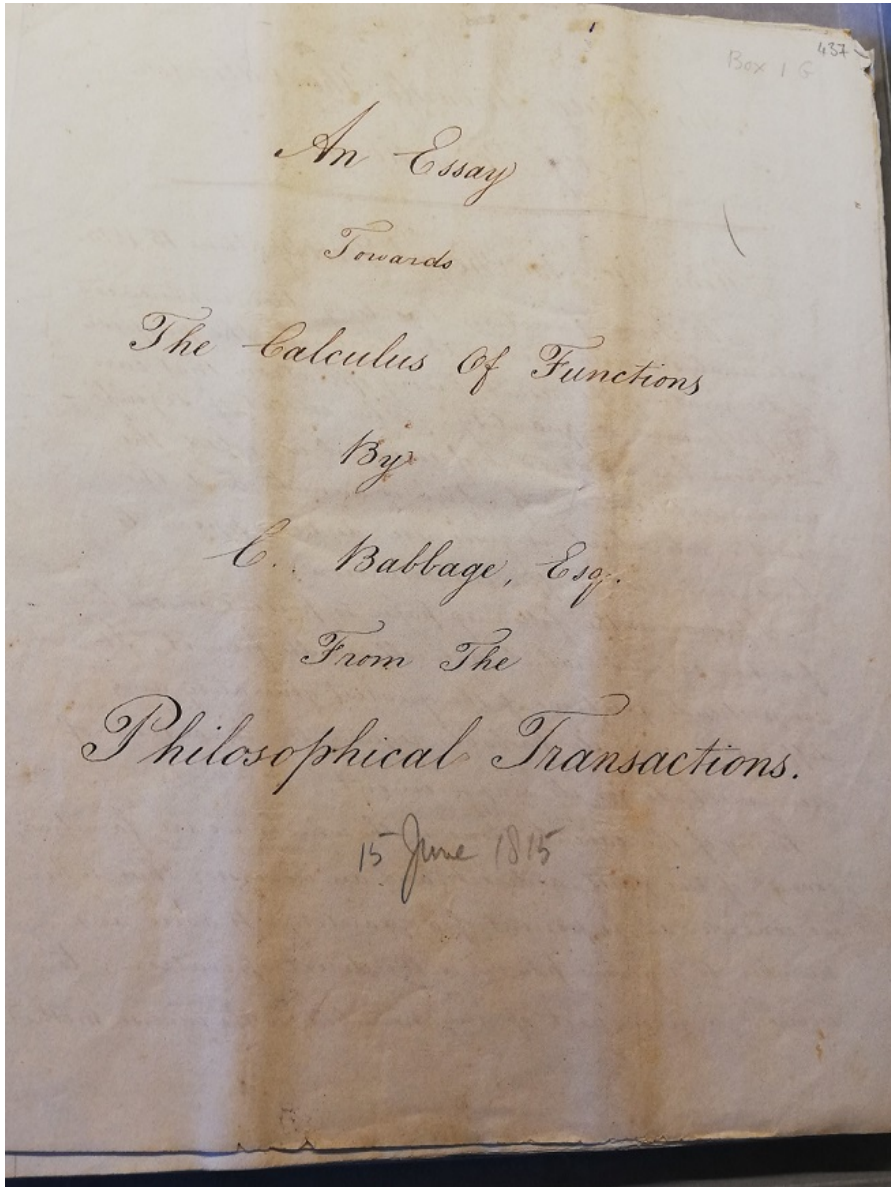
Figure 12: Front matter of manuscript copy of a *Philosophical Transactions* paper by Babbage.

tions of her second book, *On the Connexion of the Physical Sciences*, thus it seems very probable that William was borrowing these books specifically for her. Access to these expensive texts, many of which were published overseas and would otherwise have been very difficult to source, would have been indispensable in preparing and revising this work.

Whilst at a society council meeting in March of 1832, William Somerville, on behalf of his wife, solicited William Broderip (1789–1859), a magistrate, enthusiastic shell collector, and an original fellow of the Zoological Society, for information regarding plants of the Himalayan Mountains.[59] Thus even though Somerville herself could not attend the meeting where she was guaranteed to meet her acquaintances who possessed the information she required, she could send William with a directive of what she needed. The next day Broderip wrote to Somerville directly to supplement the "few hints [he] was able to give [William] during council".[60] Broderip directed Somerville to John Gould's *A Century of Birds from the Himalaya Mountains* (Gould, 1831); listed twenty flora to demonstrate that the same genera (although different species) of flowers are found in both the Himalayas and the Alps; and begged Somerville to visit the nursery of a 'Mr. Knight' before the end of spring, in order to see his specimen of the Nepalese flower Rhododendron Arboreum in bloom.

Somerville's interests within the learned societies were not just represented by her husband. Two years after meeting in Cambridge, Hamilton oversaw Somerville's election as the first female Honorary Member of the Royal Irish Academy (Brück, 2009, p. 78), (Patterson, 1983, p. 142).[61] As mentioned above, on moving to London in 1816 Somerville became closely acquainted with Jane Marcet, who helped to facilitate her election to honorary membership of the Société de Physique et d'Histoire Naturelle de Genève. While Somerville was travelling in Continental Europe in the early 1830s, she requested a copy of her *Mechanism of the Heavens* to be sent to her so she could present it to "some learned society".[62] On the request of Dr. Somerville, her publisher John Murray carried the book as far as Rome, after

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59 It is unclear from the letter which council meeting this is; both William Somerville and William Broderip were involved in the Geological Society and the Linnean Society. The 'council' of a learned society was the meeting of the fellows responsible for the running of the society, usually led by the President, Treasurer and Secretary.

60 MS, Dep. c. 369, MSB–12 367, William Broderip to William Somerville 15/03/1832.

61 Caroline Herschel was subsequently elected an Honorary Member in 1838, and Maria Edgeworth in 1842, see (O'Halloran, 2011).

62 This practice of presenting books to learned societies was very common. The notices of receipt from the Royal Society of London regarding Somerville's first two books are held in MS Dep. c. 375. Interestingly the salutation at the top of the 1831 letter

which it found its way into the possession of Jane Marcet. Somerville hoped to collect the book from her when visiting Geneva, where Marcet was living, near to her brother-in-law and physicist Pierre Prévost (1751–1839). Unfortunately, their paths did not cross, leaving Marcet with a copy of Somerville's book to dispose of. On making a call at the Prévosts, Marcet "saw... a parcel destined for [Somerville] from the Professor" and took the opportunity of writing to her.[63] Marcet suggested that the book be gifted to the Société de Physique et d'Histoire Naturelle de Genève, as "Prof[r] Prévost says they will know how to appreciate it; & it will be by them transmitted to the Bibliotheque de Genève".[64] Prévost himself had read the book in the meantime, finding it profound, clear, and above the best attempts to make the highest and most important propositions of science accessible, and it was he who requested that in April of 1834 Marcet write to Somerville informing her of her election as Honorary member of the Société de Genève.[65]

Marcet focused more in her letter on the honour done to the society by their affiliation to Somerville, than the other way around:

> after all the honors you have received this little feather is hardly worthy of waving in your plume, but I am glad that Geneva should know how to appreciate your merits. You receive great honors my dear friend, but that you confer upon our sex is still greater, for with labours & acquirements of masculine magnitude, you unite the most sensitive modesty of the female sex.[66]

Mary Frances Kater shared similar sentiments when she heard of the Royal Society's plan to commission a bust of Somerville to stand in their meeting room, saying that the Royal Society did only themselves honor through such an action (Patterson, 1983, p. 90).[67] Somerville's reputation within the scientific communities spread throughout Britain, Ireland and Western Europe clearly far exceeded that of someone 'conversant' in mathematics, and what limited official recognition was

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had to be corrected from Sir to Madam, but there was no assumed salutation on the later letter.

63 MS, Dep.c. 371, MSM–2 176, 26/08/1833
64 MS, Dep. c. 371, MSM–2 176, 26/08/1833
65 "Cette dissertation m'a frapp'e par un caractère de profoundeur et de clarité, qui la met au-dessus des meilleures tentatives, faites pour rendre accessibles les propositions les plus élevées et les plus importantes de la science." MS, Dep. c. 371, MSP–5 282, 1833.
66 MS, Dep. c. 371, MSM–2 178, 6/04/1834.
67 MS Dep. c. 371, MSK–1 41, Mary Francis Kater to Mary Somerville 12/04/1822

given her by the respective learned academies and societies was apparently a reciprocal arrangement.

Therefore, although Somerville was not directly involved in the frequent comings and goings of the social clubs and learned societies of nineteenth-century London, through the active participation of her husband and other correspondents she was nonetheless able to engage with and benefit from the easy and informal exchanging of information which took place there, irrespective of her honorary memberships.

3.4   SECRETARY

Although Somerville was a prolific letter writer and maintained a vast network of personal correspondents throughout Western Europe for much of her life, a significant proportion of her correspondence was mediated through her husband. This is especially pertinent to consider when communication of ideas at the time did not rely solely on printed texts; information was circulated within letter correspondence itself.

In February 1833 Somerville was in Paris and preparing a second volume of her 1831 translation of Laplace (see section 5.1). William, who had returned to London the previous November, mediated her communications on the subject of the compression of the Earth with astronomer Francis Baily (1774–1884), co-founder and at that time a vice-president of the RAS. Although he felt he could not add anything to what Somerville already knew, Baily used the measurements of the Earth's semi-axis and equatorial radius from George Biddell Airy's 1830 paper on the 'Figure of the Earth' to give an estimate of the compression of the Earth (Airy, 1830), and expressed his disappointment that they did not make a closer match with the compression calculated from pendulum experiments. Baily concluded his letter by asking William to reassure Somerville that he would be "at all times most happy to communicate [to Somerville] any information in [his] power".[68]

A similar informal exchange of knowledge in letters can be witnessed clearly in her correspondence with William Henry Smyth (1788–1865) and his wife Annarella Smyth (1788–1873), another example of a scientific collaborative couple. William was a naval officer who built a private observatory at his home in Bedford, Buckinghamshire. He was a member of the RAS from 1821, and was president of the same society from 1845–6. Smyth was also a prolific author contributing

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68 MS, Dep. c. 369, MSB–4 290, Francis Baily to William Somerville 03/02/1833.

papers to the journals of the RAS and the Royal Society, and was awarded the gold medal of the RAS for his 1844 book *A Cycle of Celestial Objects for the Use of Naval, Military, and Private Astronomers* (Smyth, 1844). There is little remaining evidence for Annarella's interest in science or astronomy, but she was described in her husband's obituary as "a lady of great ability and rare accomplishments, who through all his [William Smyth's] scientific labours of every description was his devoted companion and assistant" (I. F., 1866, p. 124).[69] The extant correspondence between the Smyths and Somervilles stretches from 1835 to 1870, and in the final letter, written by Somerville to Annarella, Somerville wrote: "I can never forget the friendship with which your distinguished Husband sent me notice of any remarkable astronomical event he had observed, his letters are still among my treasures".[70]

Between August and September of 1834, Somerville and William Smyth exchanged four letters in which they discussed observations of a binary star system, γ virginis.[71] This conversation took place via letter as at the time Smyth was based at his home in Bedford, 50 miles north of London, whilst Somerville's letters were sent and received from the Royal Hospital Chelsea. According to Smyth, he and Somerville had previously discussed "the rapid orbital motion of γ Virginis", and so, on his receipt of a letter from John Herschel detailing the latter's observations of the star system, he thought to pass both Herschel's and his own observations on to Somerville who might "like to know the results of this year's measurements".[72] Smyth specifically noted that the agreement between his and Herschel's observations was greater than ever before. Just under a month later Somerville replied with sentiments of delight and appreciation for the valuable information he had forwarded. At this time, Somerville was in the process of preparing her second edition of *On the Connexion of the Physical Sciences* (the first edition having been published in February of 1834), and she informed Smyth that she was currently

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69 Annarella Smyth certainly seems to have taken an interest in astronomy, as in the Somerville letters alone she gives her own description of Halley's Comet, and we learn that she attended Airy's six lectures on Astronomy in Ipswich, March 1848.

70 Held in Somerville College Library, 21/06/1870; in response to a letter from Annarella to Somerville MS Dep. c. 372, MSS–6 68, 09/06/1870.

71 A binary star system is a system of two stars which orbit each other. The discovery of such systems in the nineteenth century was seen as proof that the same force governing the solar system (gravity) did in fact govern the motions of stars and celestial bodies in far away systems (Chapman, 2015, p. 32).

72 MS Dep. c. 372, MSS–6 72, 06/08/1834. Herschel was at this time in the Cape of Good Hope conducting systematic astronomical observations from the southern hemisphere which he later published in (Herschel, 1847).
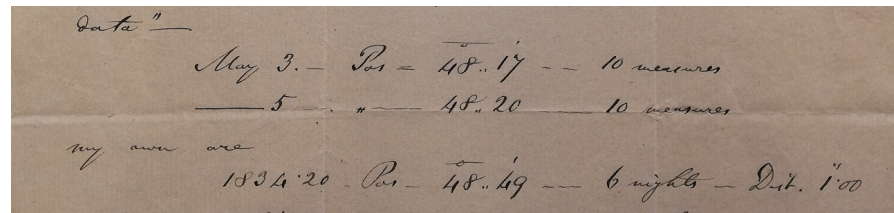
Figure 13: Herschel and Smyth's observational data of γ virginis

occupied with sending sheets to the press which took γ virginis as their focus.[73] Somerville also took this chance to request information from Smyth which would allow her to update *Connexion* with the most recent research on γ virginis, namely she asked whether the smaller star in the system attained its perihelion (the point at which it is closest to the larger star about which it orbits) on 18th August 1834 as had been predicted by John Herschel, and mentioned in the first edition of *Connexion*.

Smyth's extensive response was composed but three days later, and with it he enclosed the letter from John Herschel containing his observations from South Africa.[74] Within Smyth's letter itself he shared his most recent astronomical measurements of binary star systems, undertaken at the request of John Herschel during his absence, as well as "a few observations upon binary objects which it strikes me you [Somerville] ought to know".[75] So eager was he to help, that one week later he wrote again with position, distance, and epoch measurements for three binary star systems which he claimed did not materially differ from the measurements made at Campden Hill.[76]

Beyond sharing the observations themselves, the Smyths also encouraged Somerville to make use of their telescope in making her own observations, especially of Halley's comet. In 1705 the astronomer Edmund Halley had for the first time identified that a single celestial body was in fact undergoing periodic motion about the sun, and was responsible for comet sightings seen approximately 75 years apart. In 1757 the perihelion of the comet was predicted with error less than a month, and many mathematicians had since worked on predicting the return of Halley's comet in 1835, with the Gold Medal of the RAS

73 Somerville College Library, Mary Somerville to William Henry Smyth, 02/09/1834.
74 Smyth asks Somerville to return Herschel's letter at her convenience, and it is not held in the collection of letters at the Bodleian.
75 MS Dep. c. 372, MSS–6 72, William Henry Smyth to Mary Somerville 05/09/1834.
76 The observatory at Campden Hill, London was owned by astronomer James South. Somerville claims to have often visited South and his wife (Charlotte South, née Ellis) at Campden Hill, and to there have made observations with his telescope (Somerville incorrectly gives the name of the location as Camden Hill) (Somerville and Somerville, 1873, p. 218).

being awarded to Otto Rosenberger (1800–1890) in 1837 for "elaborate calculations relating to the return of Halley's Comet... [which] matter [is] one of the greatest importance to Astronomy" (Anon, 1839, p. 50). In his presidential address to the RAS, George Biddell Airy explained the importance of comets was because

> the very singularity and strangeness of their motion seem to hold out the very prospect of rendering to science some service, which the uniformity and similarity in the motions of the planets render them incapable of giving to us. And how are these wild bodies to be disciplined to our service? They are to be sent forth as spies; they are to go in directions in which no planets move; they are to explore spaces in which no other bodies are known to exist; and they are to return, bringing us an account, such as the physical astronomer can read, of the forces to which they have been subjected, and of the nature of the spaces through which they have passed (Anon, 1839, pp. 51–52).

Somerville herself used the return of Halley's comet as inspiration for an article written for the *Quarterly Review*, published in December 1835 (Somerville, 1835a). Ostensibly a review of two works on Halley's Comet in German, a language in which Somerville had little to no reading proficiency, it is unsurprising that the article barely mentioned these books.[77] Instead the article gave a forty-page historical review of the theory of comets, and their importance in the study of gravitation, including results from the flurry of recent scholarship which had been published since the return of the comet that September. With William Somerville incapacitated by cold, it was Gerard Moll who visited the library of the Royal Astronomical Society on Somerville's behalf to source the necessary texts. Moll, who they had met in Utrecht in 1824, was visiting the Somervilles after his trip to Dublin for the meeting of the British Association for the Advancement of Science (Patterson, 1983, pp. 166–169).

In September 1835 Annarella wrote to Somerville, following up a letter from William Smyth in which he gave notice of the return of Halley's comet, inviting Somerville to Bedford to "snatch the opportunity still remaining of seeing this interesting traveller" before it

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[77] That Somerville did not have reading proficiency in German is made clear in a letter she wrote to John Murray from Munich in 1849, where she said "It is most inconvenient being at such a distance and in a place where I have not got the necessary books of reference for as I do not read German the library has been of little use to me, besides all the best works on my subject are in English" NLS, MS 41131, 97, Mary Somerville to John Murray II, 07/03/1849.
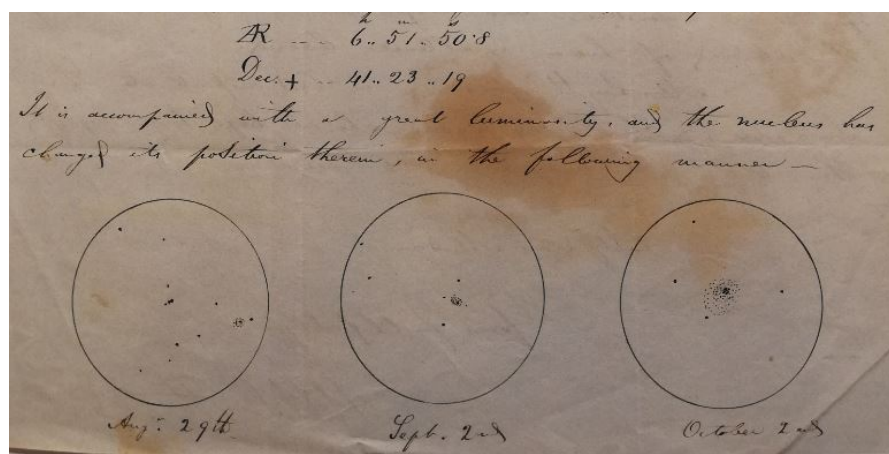
Figure 14: Drawing of Halley's Comet by William Henry Smyth, MS Dep. c. 372, MSS–6 82, William Smyth to Mary Somerville 03/10/1835.

was eclipsed by the moon in two days time.[78] Alongside descriptions of her own observations of the apparent motion of the comet in the sky, Annarella provided the practical information for Somerville to make her journey from London on the Bedford Times coach service, a speedy five and a half hour journey. Somerville was not able to make the journey at such short notice as she was awaiting her husband's return to Chelsea, but hoped she would be able to visit while the 'wanderer' was still visible.[79] A month later William Smyth again pressed Somerville to visit Bedford in order to 'inspect' the comet herself, and shared in his letters his measurements of the trajectory of the comet alongside descriptions and drawings to illustrate the evolving shape of the comet (see figure 14).[80]

The letter correspondence between the Smyths and Mary Somerville was by no means cold and formal, and the letters contain much more than just lists of data and diagrams. William Smyth shared John Herschel's complaints of the bad conditions for astronomical observation in the Cape of Good Hope, plans to visit (or not) Edinburgh for the BAAS meeting, the birth of his daughter, gossip on the recent elections of Foreign Fellows of the Royal Society, and gave thanks for the interesting details of the Somervilles' travels. Annarella Smyth's final letter, written in 1870 seemingly after an interruption in communication of several years or more, is almost entirely composed of a familial update on her children and recent news from the obser-

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78 MS Dep. c. 372, MSS–6 65, Annarella Smyth to Mary Somerville 04/09/1835.

79 Mary Somerville to Mrs Smyth, 04/09/1835, letter held in the Somerville College Library.

80 MS Dep. c. 372, MSS–6 82, William Smyth to Mary Somerville 03/10/1835. Smyth shares further observations in MS Dep. c. 372, MSS–6 84, William Smyth to Mary Somerville 05/12/1835.

vatories of Greenwich and the Cape. This last letter was motivated by the geologist Thomas Sopwith (1803–1879) who had recently been received by Somerville at Naples and passed news of her welfare to Annarella (Somerville and Somerville, 1873, p. 199).

Alongside the circulation of written items within Somerville's scientific network — books, papers, and letters — was the circulation of specimens and novelty objects. After meeting the Somervilles in Paris in 1832, Henry Ingersoll Bowditch (1808–1892), an American physician and abolitionist, paid them a visit in Chelsea where Somerville expressed her desire for a a sample of the mineral 'Green Feldspar', and on his return to the USA Bowditch sent a selection of minerals which he thought might be of interest to her (Bowditch, 1902, pp. 30–31), (Patterson, 1983, p. 110).[81] Earlier when travelling in Italy in 1817 they had been gifted many minerals from friends who had duplicate specimens (Somerville and Somerville, 1873, p. 127). Mary and William shared an interest in mineralogy, and together they learnt how to use a goniometer (which measures the angles between faces of crystals) from William Hyde Wollaston, who on his death left the Somervilles "a collection of models of the forms of all the natural crystals then known" (Somerville and Somerville, 1873, p. 129).[82] Wollaston further gifted Somerville a glass prism manufactured in Munich by Frauenhofer (Somerville and Somerville, 1873, p. 134), whilst Henry Kater gifted her a polariscope, a device for identifying gems using polarised light, small enough that Kater supposed "if a Lady... wore pockets it might be styled an interesting pocket companion".[83] Somerville herself offered an equatorial telescope made by John Smeaton to the RAS in 1844, which is now held in the Science Museum, London.[84]

When sending letters was the only way of communicating at a distance it was beneficial for your recipient to have a permanent, public address to which letters could be sent. William's position as a

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81 MS, Dep. c. 369, MSB–12 374, Henry Ingersoll Bowditch to Mary Somerville 24/2/1834.

82 In fact, a synonym for the mineral chrysocolla is *Somervillite*. Crystallographer Henry James Brooke (1771—1857) claims to have named it so, as it was given to him by a 'Dr. Somerville' along with other 'Vesuvian substances' (Brooke, 1823, p. 276). It is very possible that this 'Dr. Somerville' is indeed the husband of Mary Somerville, as she mentions him purchasing 'a number of crystals' whilst visiting Vesuvius during an eruption in 1817 (Somerville and Somerville, 1873, p. 125). I am grateful to Uwe Grimm (Open University) and Luca Bindi (Università degli Studi di Firenze) for assisting me in identifying this mineral).

83 MS Dep. c. 371, MSK–1 36, Henry Kater to Mary Somerville, 16/11/1821.

84 RAS Collection, Mary Somerville to Thomas Galloway, 12/09/1844. The telescope has object number 1931-347, and more information can be found at https://tinyurl.com/telescope-equatorial, link accessed 12/05/2021.

professional man, specifically Surgeon General at the Royal Hospital, Chelsea, meant that he was more easily contactable than Somerville; if their personal address was unknown, letters could instead be addressed to the hospital, to be forwarded on. For example, in Henry Ingersoll Bowditch's letter mentioned above, he wrote directly to Mary Somerville but addressed the letter "Mrs Somerville, to the care of Dr Somerville, Surgeon of the Royal Chelsea Hospital".[85] In his letter, Bowditch updated Somerville on the progress of his father Nathaniel Bowditch's own annotated translation of Laplace's *Mécanique Céleste*. Bowditch sent a further three letters to Somerville via the Chelsea Hospital; the last letter was sent after a period of silence lasting three years and again addressed 'care of Dr Somerville' (see figure 15).[86] Similarly, Adolphe Quetelet, the Belgian astronomer and mathematician whom the Somervilles had met whilst visiting Brussels in 1824, addressed his letter of 26th September 1827 to Dr William Somerville at the Chelsea Hospital (see figure 16); it was subsequently redirected to 6 Curzon Street (written in pencil), a house the Somervilles had rented for the social season in order to be closer to the centre of scientific and literary life (Patterson, 1983, p. 51).[87] In a society where families often moved between multiple properties according to the social season, it was far easier to inform your clubs or employer where you could be reached than informing each of your acquaintances.

Further to being a reliable point of contact, William acted as a node through which books and papers could be passed to Somerville. Quetelet accompanied his aforementioned letter with the second volume of *Correspondance mathématique et physique* to be presented to Somerville as "a small token of respect for the talents and amiable qualities for which she is distinguished".[88] This volume was edited by Quetelet and contained a French translation of Somerville's 1826 paper on magnetism, written by himself (Quetelet, 1826). In another instance the mathematician Augustus De Morgan sent William the volumes of Jean Sylvain Bailly's *Histoire de l'astronomie moderne*, asking him to present them to 'Mrs Somerville' and assure her that she can keep them as long as she would like (Bailly, 1785).[89] These books were possibly loaned from the library of the newly founded Univer-

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85 MS, Dep. c. 369, MSB–12 374, Henry Ingersoll Bowditch to Mary Somerville 24/2/1834.

86 Bowditch wished for Somerville to write a review of his father's Laplace translation to be inserted in Nathaniel Bowditch's biography.

87 MS, Dep. c. 372, MSQ–1 1, Adolphe Quetelet to William Somerville 26/09/1827.

88 "un bien foible témoignage de respect pour les talens et les qualités aimables qui la distinguent", MS, Dep. c. 372, MSQ–1 1, Adolphe Quetelet to William Somerville 26/09/1827.

89 MS, Dep. c. 370, MSD–3 126, Augustus De Morgan to William Somerville (undated).

Figure 15: Letter from Henry Bowditch addressed to Mrs Somerville, to the care of Dr Somerville, Chelsea Hospital, near London, 1838.
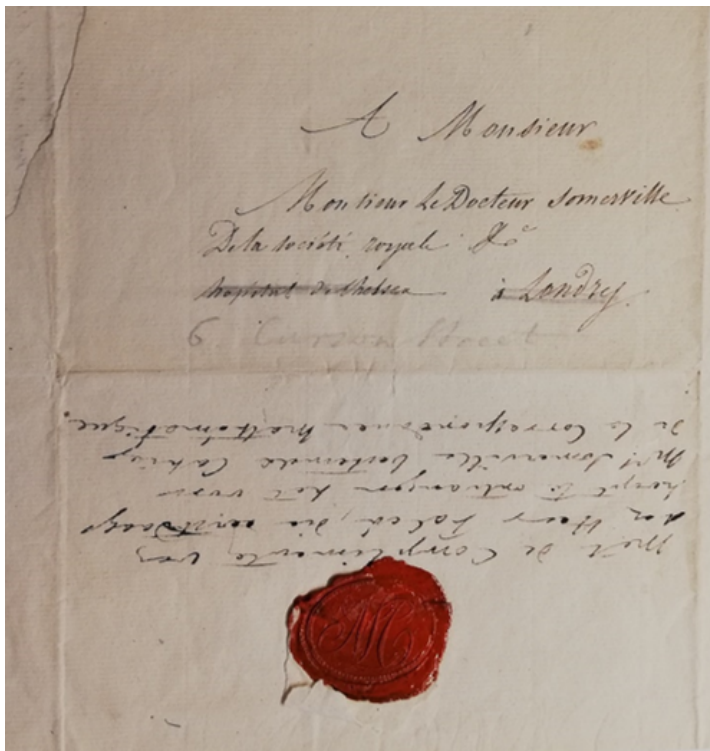

Figure 16: Letter from Adolphe Quetelet addressed to Monsieur le Docteur Somerville de la société royale &c., hospital de Chelsea à Londres

sity of London, where De Morgan was the iterant Professor of Mathematics. Three months after his resignation from University College London in July 1831 (in protest against the dismissal of a colleague), he wrote to Somerville explaining that he was "obliged... to place the books obtained from their Library for you in another name."[90] He assured Somerville that this was no reason to return the books "as long as they can be useful", directing her to return them to another professor at the college once she was finished.[91]

Two years before her election to honorary membership of the Royal Astronomical Society, at the Annual General Meeting of 1833, the Council ordered the *Greenwich Observations* to be made available to Somerville to assist in her work. The *Greenwich Observations*, or *The Astronomical Observations made at the Royal Observatory, Greenwich* was a compendium of observations published annually under the remit of the Astronomer Royal. Both the Royal Society and the RAS were granted the privilege of distributing a number of copies as they saw fit; a list of recipients was printed in the *Memoirs* of the RAS which included observatories and scientific institutions across Europe, India and the USA, as well as around 50 individuals. Somerville's name was included in Volume 5, in 1833, up until Volume 27, published in 1859, after which the lists stopped appearing (Anon, 1833).[92] In the letter from Francis Baily in February 1833 (mentioned above), Baily informed William that all volumes of the *Greenwich Observations* printed so far were ready to be delivered to Somerville. Baily suggested that they be left for William at the Athenaeum Club, where he could collect them at his convenience and ensure their safe delivery to Somerville.[93]

3.5   LITERARY AGENT

During the 1830s Somerville began utilising her acquired knowledge in order to supplement her income, through the publication of books. Her husband thus began to take on a new role, as an informal literary agent. That is to say, William took charge of the correspondence

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90 MS, Dep. c. 370, MSD–3 119, 22/10/1831.

91 MS, Dep. c. 370, MSD–3 119, 22/10/1831.

92 In 1833 Somerville was the only woman listed, but the names of many of her correspondents also feature as recipients, including Nathaniel Bowditch, John Herschel, Henry Kater, and Adolphe Quetelet.

93 MS, Dep. c. 369, MSB–4 290, Francis Baily to William Somerville 03/02/1833. William was involved with the Athenaeum Club, a private members club for those with scientific interests, from its foundation in 1824; the Athenaeum did not admit women as members until 2002.

with her publishers dealing with finances and accounts, and other business-oriented tasks necessary to publish a book (Patterson, 1983, p. 117), (Neeley, 2001, p. 69). The professional role of the 'literary agent' was not formalised until the late nineteenth century, but the gentlemen's clubs in London had long been a space for those with literary aspirations to make 'strategic friendships' or to further their business interests (Joseph, 2019, pp. 131, 133).

Although Henry Brougham had been socially acquainted with Mary Somerville since the turn of the century, it was to William he wrote when seeking an author for a translation of Laplace's *Mécanique Céleste*, and when Brougham subsequently decided that the account which Somerville had produced was too long and technical to be printed as part of his Library of Useful Knowledge as initially planned, it was William who then arranged for the work to be printed by John Murray (1778-–1843), a fellow Scot and publisher of Sir Humphry Davy's *Consolations in Travel* in 1830 (Patterson, 1983, p. 75). That it was William liaising with Murray during the preparation of Somerville's books for publication is evidenced by the titles given to the works in the accounts; the first was given as *Dr. Somerville's View of the Heavenly Bodies*, and the second as *Dr Somerville's Connexion of the Sciences*.[94] It is unlikely that these were ever serious suggestions of titles for the books, as they are not mentioned in the numerous letters which remain where potential titles were discussed.

The want of a suitable title persisted for over a year and held up the announcement of Somerville's book as "in the press". William turned to Charles Babbage and John Herschel for their assistance. "An Analytical View of La Place's System of the Mechanism of the Heavens" had been Somerville's suggested title, but there had been an objection as while she intended 'analytical' to refer to the algebraic nature of the work, it could otherwise be understood as a presumptuous claim to offer a *critique* of the work of Laplace.[95] Unfortunately, while Babbage offered his approbation of the introductory manuscript pages he had been sent, he was unable to suggest a title for the work, and we do not have a reply from Herschel.[96]

That Somerville herself solicited assistance from those scientific acquaintances she met whilst out in London society is suggested by a letter from John Elliot Drinkwater Bethune (1801—1851), a lawyer and later colonial administrator in India, in July 1831. Knowing that she was still looking for a title, Bethune wrote to Somerville to sug-

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94 MS, Dep. c. 373, MSBUS–1
95 RS, HS/16/388.
96 MS, Dep. c. 269, MSB–1 229, Charles Babbage to William Somerville 02/09/1830.

gest six possibilities; he took into consideration both linguistic concerns (the mixing of Greek and Germanic words) and that the title should make clear the work covered the motions and the internal structures of the celestial bodies.[97] Since meeting Somerville and composing his letter, Bethune had in fact discussed the title of her work with Henry Brougham and George Peacock whilst at the Athenaeum. This underlines the importance of being visible and active in the gentlemen's clubs of London; by being precluded from membership of such spaces, Somerville was unable to take part in discussions around her own work. A further paradox is that Drinkwater very possibly raised this as a topic of discussion in order to demonstrate his recently gained intimacy with Somerville, and thereby ingratiate himself with Brougham and Peacock, both of whom had vested interest in the production and success of her work.

After much deliberation, the title *Mechanism of the Heavens* was decided upon, and the book appeared in print in November 1831. Around 70 copies were presented by Somerville to her friends and contemporaries (Patterson, 1983, p. 118), many of whom replied with letters to *William* exclaiming their thanks and delight. Francis Baily thought the work invaluable for the 'improvement' of the public, and wished that he could soon pay his respects to Somerville in person.[98] Editor of the *Edinburgh Review* Macvey Napier wrote to William to discuss arrangements for a review to appear in the March edition of the journal[99] and, after hearing from John Herschel about Somerville's "great work on the *Mécanique Céleste*", Quetelet wrote to William to notify him that an announcement of the book would appear in *Correspondances Mathématiques et Physiques*.[100]

In his letter of thanks, again addressed to William, Henry Kater remarked that "Mrs Somerville has now publickly[sic] taken her station in science... [which] is a very lofty one & such as no woman ever before reached".[101] Although the 'public' and 'private' spheres have often been identified as distinct and separate in nineteenth-century Britain, with women becoming more and more confined to the domestic private sphere during this time, Kater's letter clearly highlights how the nature of Somerville's presence in these spheres, like

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97 MS, Dep. c. 370, MSD–4 134, John Elliot Drinkwater Bethune to Mary Somerville, 29/07/1831. The letter is reproduced in full in appendix C; Bethune goes on to express his envy of the celestial bodies who were not subject to corn laws nor poor laws, referring to the ongoing political unrest in Britain at the time.

98 MS, Dep. c. 369, MSB–4 289, Francis Baily to William Somerville 17/12/1831.

99 MS, Dep. c. 371, MSN–1 220, Macvey Napier to William Somerville 05/12/1831.

100 MS, Dep. c. 372, MSQ–1 3, Adolphe Quetelet to William Somerville 14/03/1832. The brief announcement was subsequently made in (Quetelet, 1832).

101 MS, Dep. c. 371, MSK–1 38, 23/04/1832, Henry Kater to William Somerville.

so many other middle and upper class women at the time, was anything but straightforward.[102] Unable to fully engage in public scientific discourse, through memberships of learned societies or appointments at universities or observatories, Somerville's mathematical and scientific pursuits nonetheless were carried out on a public stage.

William continued to assist Somerville in the preparation of her subsequent books. In 1833 he liaised with Francis Baily over the formatting and typesetting of measurements, and sent sheets to William Whewell to be proofread before publication (Patterson, 1983, p. 130). During her time in Paris between 1832–3, Somerville had discussed her next book *On the Connexion of the Physical Sciences* with the new Professor of Natural History at the University of Edinburgh, James David Forbes (1809–1868). As *Connexion* was not to be published until after the academic year had begun, Forbes reached out to William to request a manuscript copy of the work, so he could give an account of it in his lectures.[103] Two months later Forbes wrote again, thanking William for sending him the sheets of "Mrs Somerville's delightful book", noting two corrections but refusing the request of writing a review for the *Quarterly Review* citing his prior commitments.[104] Again, these letters to William came after Forbes had written directly to Somerville earlier that same year and had obviously met Somerville in person when they both visited Paris. Thus, for matters of business, as the publication of her books was seen to be, many of Somerville's correspondents preferred to communicate through her husband, who it seems was only too happy to oblige.

3.6   CONCLUSION

Somerville's belated election to honorary memberships of learned societies might suggest that she was somewhat of an outsider in the scientific circles in which she moved, but her correspondence tells a different story. Her friends and acquaintances did not condescend to her, but included her willingly and enthusiastically in their scientific networks outside of the formal institutions. Somerville's breadth of interests allowed for more meaningful engagement in this community which placed little value on specialisation or esoteric knowledge; she pursued mathematics alongside at least mineralogy, botany, and chemistry, as well as painting, poetry, and literature. Although

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102 For more on women whose lives bridged the constructed separation between the 'public' and 'private' spheres in Georgian Britain, see (Vickery, 1999).

103 MS, Dep. c. 370, MSF–2 231, James Forbes to William Somerville 20/08/1833.

104 MS, Dep. c. 370, MSF–2 233, James Forbes to William Somerville 21/10/1833.

Somerville was, and is, often spoken about as an anomaly, she was in fact part of a much wider community of women who were engaging in scientific knowledge production at the time who were unfortunately too often obscured or overshadowed by their husbands or brothers.

In contrast, the ways in which Somerville actively benefited from her marriage to William were multifaceted.

With William to act as her willing chaperone, Somerville was able to travel more freely within society and abroad, enabling her to engage personally with philosophers and savants throughout western Europe. Furthermore, by cultivating social acquaintances and friendships with her scientific contemporaries she was able to gain direct access to their experimental and theoretical results, which she actively solicited and deftly synthesised during the writing of her books.

Much of Somerville's correspondence was mediated by her husband. Sometimes this was incidental, as letters would fly between all members of households as was convenient, and commonly a single letter would contain messages for and from multiple people. Other times, this was a necessary use of William as a stable point of contact, such as when letters were addressed to his workplace to ensure safe delivery, or when items for Somerville were left at a gentlemen's club so that they could be collected at a convenient time.

Although Somerville seems to have interacted almost entirely freely via letter correspondence, or during the frequent social calls and dinners of London society, there nevertheless remained spaces in which she could not trespass. Here William acted as her representative, visiting libraries, attending society meetings, and facilitating the publication of her experimental results. Finally, as Somerville's career as an author grew, William gained a new role in their relationship by taking ownership of the business-oriented tasks that were necessary to carry a book from conception to publication.

By considering Somerville as one half of a collaborative couple, we gain a deeper understanding of the ways and means by which she engaged with the scientific community and, without a formal education, became one of the leading philosophers of the day. For fifty years William was an integral mediator and support to Somerville. Her husband was by no means the only person who took on the roles designated here as Chaperone, Representative, Secretary and Literary Agent, but this chapter underlines the importance to Somerville's career of the labour he carried out and opens up the importance of this labour to knowledge production more generally.

4

MECHANISM OF THE HEAVENS: TRANSLATION AND MATHEMATICS

The influence of Pierre-Simon Laplace's *Traité de Mécanique Céleste* on British science and mathematics in the nineteenth century cannot be overstated. A mixture of re-purposed papers and new research, the extensive work brought analytical mathematics to bear on Newtonian physics. It consisted of fifteen books published in five volumes; the first four volumes were published between 1799 and 1805 and the fifth appeared eighteen years later in 1823.[1] Laplace began with an exposition of the mathematical laws and methods by which planetary astronomy could be reduced to a problem in mechanics (Volume 1), which was followed by an analytical treatment of rotational motion, the motion of the atmosphere and the seas, and the figure (shape) of the planets (Volume 2) (Gillispie, 1997, p. 184). Methods for calculating the motions of the planets and their satellites to greater accuracy and precision were given in Volumes 3 and 4, alongside the theory of the motions of comets. In the years between the publication of Volumes 4 and 5, Laplace produced three supplements to the *Mécanique Céleste* which were printed separately after having been presented to the Institut de France or the Bureau des Longitudes (Gillispie, 1997, p. 196). Volume 5 consisted of historical information on the subjects treated in earlier volumes, interlaced with novel research carried out in the intervening years. The culmination of this work was the almost perfect agreement between the planetary motions as predicted by theory and those observed by astronomers, with any differences being attributed to unavoidable errors in observation rather than mathematics. Moreover, Laplace was able to identify and explain phenomena which were previously unknown and could not have been investigated by observation alone.

As previously mentioned, the necessity of being able to read and build upon Laplace's *Mécanique Céleste* has been recognised as one of the main catalysts for British mathematicians to adopt the differential calculus, in place of Newtonian or fluxional calculus (Grattan-Guiness, 1987, p. 53), (Guicciardini, 1989, p. 117), (Craik, 2016). Indeed in his review of Laplace's work, John Playfair described it as "the

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1 Digitized versions of *Traité de Mécanique Céleste* can be read online at https://gallica.bnf.fr/.

highest point to which man has yet ascended in the scale of intellectual attainment" (Playfair, 1808, p. 277). At least five translations into English were written between 1810 and 1840, all of which attempted to bring Laplace's results in physical astronomy to a much wider readership, as well as to make the mathematics by which they were reached more accessible to those who were not well versed in analysis.

We do not here suggest translation as the process of mechanically reproducing a text in a foreign language, but understand it as an active process which can require critical engagement with the source text and offers the translator scope to make original contributions to scientific knowledge (Martin, 2015), (Orr, 2015). Such a claim about Somerville's *Mechanism of the Heavens*, a partial translation of Laplace's *Mécanique Céleste*, is not new. Previous scholarship has displayed how as translator Somerville took on the roles of guide, critic, interpreter of Laplace, and historian of science (Neeley, 2001, pp. 97–99).[2] Certainly, one of the greatest changes she made was introducing numinous themes throughout, relating the study of the solar system to a study of Creation and presenting Laplace's work as a way to experience "the divine transcendence of God" rather than as a path to materialism (Secord, 2014, p. 131).

Rather than focusing on the narrative or rhetoric methods that Somerville employed, this chapter presents the first critical study of the mathematical work that Somerville carried out during the translation process. We begin with a consideration of the translations written before *Mechanism of the Heavens* to investigate the types of changes that were deemed necessary to render *Mécanique Céleste* accessible to a British readership, such as changes in notation, explanations of methods, or references to secondary literature. Somerville's correspondence with John Herschel shines a light on the questions Somerville herself grappled with in translating Laplace, and the solutions she found. Finally, the mathematics Somerville included in her work and contemporary reviews are scrutinized in order to investigate the often made claim that *Mechanism* was a 'popularization', and that it succeeded in making "the conclusions and methods of [Laplace] more accessible to mathematically competent English-speaking readers" (Carlyle and Wallace, 2013, p. 141).

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2 The place of Somerville and her *Mechanism of the Heavens* in the history of scientific translations produced by women, and the expansion of educational opportunities have been treated in (Carlyle and Wallace, 2013) and (Secord, 2004, ix, Vol 1) respectively.

4.1   EARLIER ENGLISH TRANSLATIONS OF *mécanique céleste*

Although not a translation, a key work which brought Laplace's *Mécanique Céleste* to the attention of the British scientific community was John Playfair's 1808 review published in *The Edinburgh Review* (Playfair, 1808).[3] Playfair claimed that astronomy was "at the head of the physical sciences" as it provided an explanation "so complete, that there is not any fact concerning the motions of the heavenly bodies... which is not reducible to one single law — the mutual gravitation of all bodies to one another" (Playfair, 1808, p. 249). The review began with a brief historical overview of the mathematics used by Laplace, highlighting the most important recent developments in integral calculus which enabled mathematicians to extend "the philosophy of Newton to its utmost limits" (Playfair, 1808, p. 250). Playfair noted: the application of algebra to trigonometry by Leonhard Euler, especially his 'convenient notation'; the discovery of the method of partial differences by Jean le Rond d'Alembert; the invention of '*Calculus variationum*' (calculus of variations) by Joseph-Louis Lagrange; methods of quadrature and solving 'fluxionary equations of all orders', especially those by Euler; and the mechanical principle of equilibrium, discovered by d'Alembert and improved by Lagrange, which enabled mathematicians to express all problems concerning the motion of bodies as "fluxionary or differential equations" and thus solve them via mathematical computation.[4] Playfair then gave a brief description of the contents of each of the four volumes of *Mécanique Céleste* which had at that time been published, adding his own thoughts on the technical and historical context of the work.

The first English translation was written by John Toplis (1775–1857) and published under the title *A Treatise upon Analytical Mechanics; being the first book of the Mechanique Celeste of P. S. Laplace* (Toplis, 1814).[5] Toplis had graduated from Queens' College Cambridge in 1801 as 11th Wrangler in the Mathematical Tripos. At the time of writing his translation he was the headmaster of Nottingham Free Grammar School and had recently been elected a fellow of Queens' College (Gielas, 2018). The title page of the book noted that it was printed in Nottingham, but listed booksellers in London and Cambridge where

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3 For information on the importation of *Mécanique Céleste* into Britain immediately after its first publication, see (Topham, 2011).

4 All uses here of 'invented' or 'discovered' are Playfair's own.

5 Whilst this work and the ones that follow are not necessarily *literal* translations, I will still refer to them as translations with the understanding that this leaves space for the translator to insert original material and make non-trivial edits during the translation process.

there would certainly have been a larger readership for the work. Nothing beyond the first book of *Mécanique Céleste* was translated into English by Toplis.

Seven years later a second English translation of the first book was published anonymously by Somerville's publishing house, John Murray (Young and Laplace, 1821). The uncredited author was Thomas Young (1773–1829), a London-based physician whose interests spanned most of natural philosophy; he had studied at universities in Edinburgh, London, Göttingen and Cambridge, and had been elected a fellow of the Royal Society of London in 1794, aged just 19. From 1801 to 1803 he was Professor of Natural Philosophy and Chemistry at the Royal Institution, and this is the same Young who showed the Somervilles an Egyptian papyrus in the 1820s (see section 3.2). Young is well remembered in mathematics through his contributions to the theories of waves and light (Craik, 2010).

It was an Irishman,[6] Henry Harte, who was the first to produce an English translation that went beyond Book 1; his version of Book 1 was published in 1822, followed by Book 2 in 1827, which together made up the entire first volume of *Mécanique Céleste*. Harte had graduated from Trinity College, Dublin in 1809, and was elected a fellow there in 1819. In his lifetime he published translations of multiple French works including Poisson's 1833 *Traité de Mécanique*, and the fifth edition of Laplace's *Exposition du Système du Monde*. Both books were printed in Ireland by Richard Milliken, bookseller for Trinity College, but the London bookseller Longman, Hurst, Rees, Orm, and Browne was listed on the title page of the first book only (Grattan-Guiness, 1987). This bookseller was in fact the same London distributor of Toplis' 1814 translation.

The fourth and most comprehensive English translation of *Mécanique Céleste* was by Nathaniel Bowditch (1773–1838), an auto-didact who worked as an actuary in Boston, Massachusetts, USA. Bowditch was aware of the three preceding translations, and makes mention in his translator's introduction of having made "occasional use" of those of Toplis & Young, but was unable to get a copy of Harte's (Bowditch and Laplace, 1829, p. vii). Bowditch prepared his extensive notes on the text on reading the volumes of Laplace's work as they were published, with the translation being completed in the years 1815–17; he claims that publication was postponed in the hope that Laplace would produce a new edition of the first volume which would take into account recent research and improvements made by Poisson and

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6 Since the Act of Union 1800, Ireland had been part of the United Kingdom of Great Britain and Ireland.

Ivory, but this never materialised (Bowditch and Laplace, 1829, pp. vi–vii). By sending copies of his work to learned societies and his scientific acquaintances throughout the USA, Europe (predominantly Britain and Ireland, and France), and India, Bowditch ensured that his work was widely circulated (Bowditch and Laplace, 1839, pp. 166–8). The work was very well received by the scientific community, and became the definitive English translation.

Bowditch, Young, and Harte all intended to produce translations of the entirety of *Mécanique Céleste*, and indeed Young hoped to encompass treatments of other works in astronomy and 'higher mathematics' in the scope of his project (Young and Laplace, 1821, p. i). The delineation between the different books and volumes of the original work were not maintained by the translators, and as mentioned above it was only Bowditch who managed to progress past Book 2. Whereas Toplis and Young both described their readers as students, Harte stated his objective was to "render this work accessible to the general class of readers". Bowditch identified his reader as someone acquainted with elementary treatises on spherical trigonometry, conic sections and fluxionary or differential calculus, but offered additional advice to any young people reading the work for the first time.[7]

There are many common themes running through the translations regarding the superiority of French mathematics and the difficulty of making the esoteric analytic mathematics used by Laplace accessible to a wide readership. I will discuss each of these themes in turn, identifying where differing views of the authors led to differences in the style of translation adopted.

Firstly, the final five pages of Playfair's thirty-six-page review were dedicated to his reflections on the decline of British mathematics and physical astronomy. He noted the almost complete absence of British mathematicians in a list of those who contributed to the development of new mathematical methods and their applications to physical astronomy in the preceding seventy years. He gave only two exceptions, the work of Colin Maclaurin (1698–1746) on the attractions of ellipsoids and the work of Mathew Stewart (1717 –1785) in his *Physical Tracts* (Stewart, 1761), but regretted that the latter was presented using methods of ancient geometry rather than "the more powerful analysis of modern algebra" (Playfair, 1808, p. 280).[8] Playfair felt that this could not be attributed to a lack of motivation, owing to the in-

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7 Namely to omit chapters 4, 6 and 8 of Book 1 until they have read Book 2.
8 For more on the influence of Maclaurin's *Treatise of Fluxions* (MacLaurin, 1742) on continental mathematics, see (Grabiner, 1997). When Maclaurin passed away, Stewart replaced him as professor of mathematics at the University of Edinburgh.

trinsic utility of physical astronomy in navigation, but must instead be attributed to an inability to engage with even elementary continental texts. Referring back to the areas of mathematics which he had listed as "essential or highly conducive to the improvements in physical astronomy", Playfair noted that the method of partial differences was not yet treated by a single English author, and the best treatises on the fluxionary calculus by a British author were those of Maclaurin and Simpson which were already over half a century old and therefore written before the "vast multitude of improvements... made by the foreign mathematicians" (Playfair, 1808, pp. 280–281).[9]

Disappointment at the stagnation of British mathematics was a sentiment shared by John Toplis, who a decade before his translation of Laplace wrote an article for the *Philosophical Magazine* titled 'On the decline of mathematical studies and the sciences dependent on them' (Toplis, 1804). Similarly to Playfair, Toplis observed that for the preceding half-century philosophers had been "sunk into a great degree of supineness with respect to the sciences" (Toplis, 1804, p. 26). He gave an extensive quote from John Robison's article 'Physics' in the *Encyclopaedia Britannica*, where the Edinburgh professor of Natural Philosophy (and hence colleague of Playfair) gave his own lamentation that the taste for mathematics had waned so greatly in Britain. In the quote Robison described his mortification that Newton was "indebted to the services of a Belidor, a Bossuet, a Clairaut, a Boscovich" for the cultivation of his work (Toplis, 1804, pp. 27–28).[10] Writing to a friend in 1798, Thomas Young wrote that he was "ashamed to find how much the foreign mathematicians for these past fifty years have surpassed the English.. [they] have given solutions to problems which have scarcely occurred to us in this country" (as quoted in (Craik, 2010, p. 102)).

The neglect of continental mathematics had lasted so long that it was insufficient to merely take note of current progress; the communities had diverged to such an extent that works produced on the continent were now incomprehensible to a British reader. It was for this reason that Toplis chose to translate what he described as an *elementary* treatise on 'analytical mechanics' with additional explanatory material (the format of which we will discuss in depth below). That is, he chose the first Book of *Mécanique Céleste* where Laplace introduced the necessary mathematics to begin studying the celestial mo-

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9 The works referred to here are (MacLaurin, 1742) and (Simpson, 1750). This perceived neglect by British mathematicians of work done on the continent is a recurring theme in Playfair's reviews, which he used to draw attention to treatises he deemed as important (Ackerberg-Hastings, 2008).

10 For more on Playfair and Robison, see (Morrell, 1871).

tions. Toplis aimed the text at students whose previous studies had not exceeded "the elementary principles of mechanics and of fluxions as taught in this island", but who wished for the necessary knowledge to read and understand *Mécanique Céleste* in its entirety. Toplis noted that the only remaining obstacle to a reader after completing his treatise would be a knowledge of integration, and thus directed them to treatises on integral calculus, particularly Lacroix's *Traité du calcul différentiel et du calcul intégral* (Lacroix, 1797–1800), (Toplis, 1814, pp. iii–iv). Although writing from the United States of America, and thus not necessarily concerned with the decline of British mathematics per se, Bowditch was nevertheless mindful of a disparity between the mathematical methods used by Laplace and those of his potential readership. The volume and extent of his additions were increased by the need to explain elementary principles used by Laplace that were not yet commonly taught in schools and colleges in the USA (Bowditch and Laplace, 1829, p. vii).

A common theme shared by all the authors but Bowditch, is the constructed opposition between geometry and analysis, the former of which was associated with the inferiority of British mathematics, and the latter a key factor in the superiority of continental mathematics. In part, the eminence of *Mécanique Céleste* itself was derived from Laplace's comprehensive *analytical* treatment of physical astronomy. In his 1804 article on the decline of mathematical studies Toplis noted the "wonderful and matchless powers of modern analysis", finding it remarkable that British mathematicians "still obstinately attach themselves to geometry" (Toplis, 1804, p. 28). Ten years later, he linked an increasing taste for works by continental mathematicians to his hope that "analytical sciences will again flourish in the country of their illustrious founder", implicitly referencing the work of Isaac Newton (Toplis, 1814). Although Harte made no reference to the decline of British mathematics, he explicitly used his translation to encourage his readers to engage with and adopt analytical methods. By identifying the disparate propositions of Newton which come under a single law when described analytically, he wanted to demonstrate "the great superiority of the analytic mode of investigating problems" (Harte, 1822, p. vi). Young was more equivocal in his attitudes towards analysis and geometry, both in his translation and in his wider body of work (Craik, 2010). He situated his translation as a bridge between "geometrical and algebraical modes of representation", claiming it was readable by English mathematicians who are "conversant with... the old school only" (Young and Laplace, 1821, p. iii). In order to aid the memory and apprehension of his student

Translation	Language		Notation	
	Fluxional	Continental	Fluxional	Continental
Toplis		✓		✓
Young	✓		✓	✓
Harte		✓		✓
Bowditch		✓		✓

Table 2: Table of notation uses

readers he divided the text "into distinct propositions, enunciated at the beginning of each investigation", completely rewriting Laplace's work as a series of verbose definitions, theorems, and scholia (Young and Laplace, 1821, p. ii). He conceded that this was a departure from "strict analytical order", but did not feel that this undermined his translation.

As discussed in section 2.3, a key choice to be made when writing about continental mathematics was that between the use of fluxional or differential notation.

As can be seen in table 2, all but Young exclusively used the notation and language of continental (differential) calculus, as used by Laplace.[11] Whilst practically the choice was somewhat trivial—as noted by Playfair it was easy to move between the two notations—there had been long ongoing debates about which formalism of the calculus was the more theoretically sound. This is illuminated in a page-long scholium buried within Young's chapter on 'simple accelerating forces' in which Young justified his use of differentials rather than fluxions. He noted the predilection in Britain to use the method of fluxions in order to "preserve the geometrical accuracy introduced by [its] great inventor", again making implicit reference to Newton (Young and Laplace, 1821, p. 76). Young seemed to suggest that this accuracy came from considering the *finite* ratios of the increments of two quantities x and y, rather than the *evanescent* increments themselves. He refered to the authority of Euler to support his claim that the "language of the English" was the more correct, but conceded Euler's point that the continental notation was more convenient, giving the example of taking the differentials of a variation.[12] Young then constructed a linguistic equivalence between the differential, dx,

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11 Toplis does refer to the "integral or fluent" of a quantity early in the work, but occurrences of 'fluent' are singular and always in conjunction with 'integral' (Toplis, 1814, p. 5).

12 $d\delta x = \delta dx$ being preferable to $(\delta x)\cdot = \delta\dot{x}$.

and the fluxion, $\dot{x}$, with both representing "a finite quantity proportional to an evanescent element", thereby justifying his use of differential notation alongside fluxional language (Young and Laplace, 1821, p. 77).[13]

In contrast, Bowditch explicitly noted the faithfulness of his translation, both for preserving the sense of the author when moving from French to English and for its strict adherence to the notation used by Laplace, even retaining double parentheses to denote partial differentials which Bowditch admitted was by that time widely rejected by mathematicians (Bowditch and Laplace, 1829, p. vi). Bowditch even maintained the decimal division of degrees, giving the equivalent sexagesimal measurement in the footnotes. Whilst Young clearly wanted to make the ideas and results contained within Laplace's work more visible and accessible to a British mathematical readership, Bowditch instead aimed to showcase and promote the *Mécanique Céleste* itself in as close to its original form as possible. These differing aims of the translators also resulted in differing practices when inserting new material.

Young's *Elementary Illustrations* began with an entirely new fifty-four-page introduction on the "rudiments of mathematics", which included definitions for such basic concepts as the equals sign and addition and subtraction, alongside an introduction to fluxions. As well as reformatting the work into theorems and scholia, Young "extracted, from his own former publications, such parts as he felt himself compelled to substitute for Mr. Laplace's introductory investigations, but without omitting, as collateral illustrations, such of Mr. Laplace's demonstrations as appear[ed] to be the most ingenious and satisfactory" (Young and Laplace, 1821, p. ii). Furthermore, he gave an account of his theory of the cohesion of fluids in an appendix in which he does not mention Laplace. This is somewhat surprising considering that they had been brought into direct conflict through a priority dispute over the formula for the change in pressure across a fluid interface of double curvature (Craik, 2010, p. 109). Young also incorporated materials from authors other than himself, such as in the final chapter on the motion of fluids, which began with a seven-page extract from Poisson's *Traité de Mécanique* (Poisson, 1811).

Unlike Young and Toplis, who explicitly inserted material in order to create a bridge between British and French mathematics, Harte and Bowditch used footnotes to bridge the intuitive leaps or com-

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13 Perhaps nitpicking, Young also noted the difference between dx, as printed in the works of Laplace, which in fact should be used to represent the product of d and x, rather than the correct dx as in the work of Lacroix (Young and Laplace, 1821, p. 77).

In the motion of a particle upon a surface, the pressure arising from the centrifugal force, is equal to the square of the velocity, divided by the radius of curvature of the curve described by the particle, and multiplied by the sine of the inclination of this circle of curvature to the tangential plane of the surface :* by adding to this pressure what arises from the action of the other forces acting upon this particle, we shall have the whole pressure of the particle against the surface.

[54''']

We have proved [54] that if the particle is not acted upon by any force, its pressure against the surface is equal to the square of its velocity, divided by the radius of curvature of the described curve ; the plane of the circle of curvature, that is, the plane which passes through two consecutive points of the curve described by the particle, is in this case perpendicular to the surface.† This curve, relative to the surface of the earth, is what is

[54'']

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* (20) To illustrate this, suppose the particle to move upon the surface $AEDF$ of a right cone, whose axis is CB, and to describe, with the velocity v, the circumference of the circle $AEDF$, whose radius $r = BD$ is perpendicular to CB. Continue BD to H, making $DH = \frac{v^2}{r}$, draw HG perpendicular to CD. Then, by [54], while the particle is at D, moving towards F, its centrifugal force f in the direction BD, will be represented by $f = DH = \frac{v^2}{r}$, and this may be resolved into two forces DG, GH, of which the former, being parallel to the side of the cone, produces no pressure, the latter, GH, represents the actual pressure $P = GH$. Now if we put I equal to the inclination of the circle $AEDF$ upon the plane which is a tangent to the conical surface at D, it is evident that $I =$ angle $BDC =$ angle GDH. But by trigonometry

[54b]
$GH = DH . \sin. GDH$, or in symbols $P = f. \sin. I = \frac{v^2}{r} . \sin. I$, as above. What is here said of a cone will evidently apply to any other surface, supposing always the axis BC to be drawn through the centre of the circle of curvature perpendicular to that circle till it meet in C the plane which is the tangent of the proposed surface at the point D.

† (20a) Comparing the expression of the pressure [54] $\frac{v^2}{r}$ with that in [54b], we get $\frac{v^2}{r} = \frac{v^2}{r} . \sin. I$, whence $1 = \sin. I$; therefore the inclination I must be a right angle.
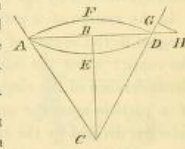
Figure 17: Page 44 of Bowditch's translation of *Mécanique Céleste*, treating centrifugal forces. The footnotes, added by Bowditch, are separated from the main text by the horizontal line.

putational skips made by Laplace. Both Bowditch and Harte noted the difficulties of filling in the intermediate steps in the workings of Laplace as the greatest barrier to understanding the *Mécanique Céleste*. Laplace's tendency to skim past intermediate steps of reasoning was noted not just by anglophone readers, but also by Jean-Baptiste Biot when telling an anecdote to the Académie Française in February 1850. Biot had requested to see the sheets of *Mécanique Céleste* as they were printed, and in return offered to indicate to his patron Laplace any typographical errors he discovered before the final publication. On coming to Laplace for assistance to understand the text, Biot once "saw him pass almost an hour trying to seize again the chain of reasoning which he had concealed under this mysterious symbol, *il est aisé de voir* [it is easy to see]" (Biot, 1850, p. 67).[14] The extent of the additions deemed necessary by Bowditch can easily be witnessed by the fraction of the page dedicated to his additional footnotes (for which figure 17 is a representative example); Bowditch's Volume 1 ran to over 720 pages, twice the length of Laplace's.

All four translations of *Mécanique Céleste* into English were motivated by a need to render the work accessible to anglophone readers, not because of a lack of knowledge of the French language, but because of the esoteric mathematics it contained. All authors conceded the superiority of differential over fluxional notation, but Thomas Young maintained that there were situations in which synthetical methods were preferable to the analytical. The authors also differed slightly in their motivations, between wanting to improve the quality of materials on physical astronomy available in Britain, Ireland, and the USA, to wanting to broaden the readership of the *Mécanique Céleste* itself.

4.2 SOMERVILLE COMMISSIONED TO WRITE A TRANSLATION

In 1826 the Society for the Diffusion of Useful knowledge (SDUK) was founded by Henry Brougham, a friend of Somerville and prominent advocate for reforming society through knowledge and reading. The 1820s in Great Britain had witnessed intense political unrest, anchored by debates over parliamentary reform which led to the passing of the Roman Catholic Relief Act 1829, and the Representation of the People Act 1832. Whigs saw self-education as a solution to this unrest, as well as the religious and social crises being driven by technological advancements. The SDUK attempted to democratize scientific

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14 Translation of Biot's anecdote as given in (Lovering, 1889, pp. 197–8), attributed to 'a lady'.

knowledge by issuing works which were cheaply bound, and printed in weekly installments as small octavos with dense font. The society's most successful work was the *Penny Magazine* which achieved a circulation of over 200,000 copies (Secord, 2014, pp. 16–19).

In March 1827 Brougham wrote to William Somerville detailing his plans for an account of Laplace's *Traité de Mécanique Céleste* which would "explain to the unlearned the sort of thing it is — the plan, the vast merit, the wonderful truths unfolded or methodized — and the calculus by which all this is accomplished". He envisioned two treatises, of between 100 to 800 pages each, one of which would give "the more popular view, and another the analytical abstracts and illustrations" (Somerville and Somerville, 1873, p. 161). In spite of the three English translations which had already been printed and sold in Britain, Brougham claimed that fewer than one hundred people knew the work by name and no more than twenty had engaged with the work in any depth whatsoever.[15]

Although she never published any mathematical research papers, Somerville's reputation as an expert in French analytical mathematics certainly placed her in this elite group of mathematicians. Having met Somerville in Chelsea in the early 1820s, American physician Charles Caldwell (1772–1853) described their meeting in his posthumously published autobiography as follows. After spotting a volume of Laplace on her bookshelf, Caldwell turned the conversation to astronomy "respecting which [Somerville] conversed with such a familiarity and compass of knowledge as might have led to a belief that she had just returned from a tour among the heavenly bodies" (Warner, 1855, p. 380). As well as building her reputation by impressing individuals with her erudite conversation, she received the approbation of Laplace himself as evidenced in his 1824 letter, and cultivated an extensive collaborative network of scientific acquaintances (see section 3.2).

Moreover as an auto-didact and a woman, Somerville was an exemplar of the intended reader of the proposed work, whose authorship could inspire a wider demographic of people to engage meaningfully in the project of the SDUK (Secord, 2014, p. 112). When writing to William asking him to help secure Somerville as the author of this account, Brougham suggested that if Somerville would not undertake the project then it would have to be left undone as no one else could complete such a work.

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15 Bowditch's translation had not by this time been printed, and it does not appear that the others sold particularly well. Apparently Toplis was left with nearly 250 unsold copies of his (Gielas, 2018).

In her *Personal Recollections* Somerville marks this letter as the nexus of her project to translate the work of Laplace, and to transform it into a version understandable for a British readership (Somerville and Somerville, 1873, p. 163). Buried within performative false modesty regarding her mathematical skills, in which Somerville defends her audacity in undertaking such a difficult project by making explicit that she did so only after the personal urging of Brougham, she outlines the difficulties she herself saw in completing the translation: Her potential readers would have to be already somewhat familiar with differential and integral calculus; she would have to add supplementary proofs of problems in physical mechanics and astronomy; and she would have to introduce diagrams and figures.

In addition, Somerville faced difficulties as a woman who was expected to raise children and entertain her social acquaintances alongside the preparation of her work. Somerville reflected in PR how she learnt to "leave a subject and resume it again at once, like putting a mark into a book [one] might be reading", necessitated by the frequent social visits paid on her at Chelsea which etiquette required she receive. In an editorial note Somerville's daughter Martha interrupts the first person narrative to share how her mother used this skill to great advantage when completing her domestic duties. When teaching her young daughters grammar or arithmetic Somerville would always patiently answer their questions on "tense or gender, or how much seven times seven made... and return calmly to her own profound thoughts" (Somerville and Somerville, 1873, p. 166). Moreover, Somerville's powers of concentration were sufficient that she did not need to "isolate herself from the family circle in order to pursue her studies" (Somerville and Somerville, 1873, p. 165).[16] The need to balance domesticity and mathematical research was apparently further complicated by Somerville's desire to keep her work a secret, so that if she "failed" in her task, the manuscript could be "put in the fire" (Somerville and Somerville, 1873, p. 163). Although Brougham recognised her as the only person capable of such a task, Somerville would nonetheless have faced intense scrutiny from the outset should her project have become widely known. The novelty of such a work being written by a woman would have been agreed by all, but the *desirability* formed the basis of heated debate. Therefore it is understandable that Somerville felt the need to hide her papers as soon as anyone came

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16 These comments would certainly have served to reassure the Victorian reader that a study of mathematics was not completely incompatible with a woman's domestic responsibilities in the home, nor did it render her undesirable company in polite society as was usually expected of a bluestocking.

to call, and was loathe to use her work as an excuse to turn visitors away.

However, Somerville did not complete her work in absolute isolation. From at least as early as March 1829, Somerville began requesting advice and assistance from her mathematical and scientific contemporaries, most notably from John Herschel and John William Lubbock (1803–1865), a member of the SDUK who published numerous papers on celestial mechanics, tides, and probability. As seen in Chapter 3, this sharing of information was not uncommon in Somerville's milieu and indeed Lubbock turned to Somerville for assistance with his own work, asking her to check his 'moon calculations' before they appeared in print and requesting her comments on his paper on comets.[17]

In her first letter to Herschel thanking him for his criticisms on her work, nearly two years after Brougham had solicited the translation, Somerville refered to her manuscripts as forming merely a "paper", suggesting that she had not yet progressed very far.[18] She informed Herschel that she was then employed with the second book of Laplace. A year later Somerville announced to Herschel that she had finished her work on the moon and satellites which completed what she intended to include in her partial translation of *Mécanique Céleste*. According to her, whether the whole or any part ever went to the press depended on Herschel's advice which she knew would be "given with the truth of a friend".[19]

By March 1830 there was great uncertainty as to whether Somerville's book would be published — and if so, by whom. Herschel was intimately involved in the decision process, liaising with not only Somerville, but also the two prospective publishers, Henry Brougham and John Murray. Somerville had been considering "separate publication" since at least February of that year, according to a letter written to her by Herschel. It is unclear what prompted Somerville to consider publishing her work, which at this time was almost reaching completion, outside of the auspices of Henry Brougham and the SDUK who had originally commissioned it. Patterson, relying on an early draft of Somerville's *Personal Recollections*, suggests that Brougham himself had worried that Somerville's translation was not suitable for

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17 MS Dep. c. 371, MSL–5 132 & 135, both undated, John William Lubbock to Mary Somerville.

18 HS/16/327. The letters between Mary Somerville and John Herschel regarding the preparation of *Mechanism* are transcribed in Appendix D.

19 HS/16/331.

the SDUK (Patterson, 1983, p. 71).[20] This is further supported by a letter written from Brougham to Somerville in September 1840 (and reproduced in PR), where he complains of the difficulties he found in writing an account of the *Mécanique Céleste*:

> I have almost abandoned [it] in despair after nearly finishing it; I find so much that cannot be explained elementarily, or anything near it. So that my account to be complete would be nearly as hard as reading yours, and not 1000th part as good... (Somerville and Somerville, 1873, p. 237).

In the memoir and personal correspondence of John Murray, edited by Samuel Smiles, Smiles suggested Somerville's translation was found "too voluminous" and "above the class for whose instruction it had been intended by Mr. Brougham" (Smiles, 1891, p. 406). In his collected works of Somerville, Secord claims that her 620-page treatment fit the brief she was given, and rather suggests that Brougham was no longer confident in the appetite for esoteric mathematical texts, due to the falling sales of his Library of Useful Knowledge, and thus reneged on his offer to publish (Secord, 2014, p. 115).

What is clear, is that in August 1830 John Murray contacted William Somerville agreeing to publish the work at his own cost and risk, and offered to pay Somerville two thirds of any profit that was made from the venture and to allow her to keep ownership of the copyright (Patterson, 1983, p. 75). Herschel's perception of the "excellence of Mrs. Somerville's [manuscripts]" was a key factor in Murray's decision to publish; therefore although Somerville knew that Herschel's criticisms would be given with the truth of a friend, their importance were as from an expert in analytical mathematics and physical astronomy.

4.3 TRANSLATION AS MATHEMATICAL PRACTICE

We now turn to Somerville's correspondence with John Herschel during the preparation of *Mechanism of the Heavens* to further investigate the mathematical work required during the translation and writing process.[21] There are 19 letters in the Herschel Correspondence, held at the Royal Society of London, in which Herschel and Somerville discussed changes and improvements to be made to the manuscripts

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20 Owing to Covid-19 restrictions, I have been unable to visit the Bodleian Library in order to view the relevant passage myself. See section 2.1 for the limitations of the *Personal Recollections* as a primary source.

21 See (Haffner, 2017) for editorial work as mathematical activity.

of *Mechanism*. Of the letters which are dated, the dates lie between March 1829 to June 1831.

As mentioned above, the earliest letter is dated March 1829 and the letter is warm with friendship. Somerville expressed her gratitude that Herschel was forgoing time with his new bride in order to read her work, describing this as "a very great mark of friendship". Herschel had very recently married Margaret Brodie Stewart (1810–1884), whose own scientific interests included botanical illustrations.[22] Somerville invited the newlyweds to Chelsea so that she and Dr Somerville could become acquainted with Brodie Herschel, saying it would be her pride to consider her a friend, and their warm correspondence did last for nearly forty years. The feelings of friendship and intimacy were certainly reciprocal between the two families. Having unexpectedly received a fee for his review of *Mechanism* in the *Quarterly Review* (see section 4.5) Herschel informed William Somerville that he had "asked Lady H what ornament she thought most appropriate to the occasion & she told me she thought the best ornament of a wife was to be out of debt & ordered me to pay her milliner's bill, to which laudable purpose [the fee] will be applied tomorrow".[23] Somerville herself was also asked to be the Godmother of the Herschels' daughter Matilda Rose in 1844.

Although Herschel was an intimate friend, Somerville nevertheless deferred almost entirely to his expertise, and most of her letters to him regarding *Mechanism* assumed a noticeably deferential tone; she was "truly obliged [for his] criticisms" which she assured him she would gladly adopt in their entirety.[24] Somerville seems to have been reluctant to go to press without the approbation of Herschel, as she later apologised for sending him revised sheets explaining that she "really should feel uneasy without [his] opinion as to the changes [she] made", and if he deemed it necessary she would re-write yet again the passage under consideration.[25] In May 1830 she shared her hesitation to print the work "without knowing that it does not contain any great blunders", which it appears were the responsibility of Herschel to point out.[26]

Somerville's hesitation could have been due to the intense scrutiny which her book would face, arising from the difficulty and the cultural importance of the work which she was attempting to translate

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22 For more on Brodie Herschel and her botanical paintings see https://tinyurl.com/brodie-herschel-photography, accessed 13/05/2021.
23 HS/16/402.
24 HS/16/327.
25 HS/16/331.
26 HS/16/336.

and elucidate. Herschel himself admitted to Somerville that his fluency with the *Mécanique Céleste* was limited. In June 1830, he apologised for holding on to the manuscript pages of the first complete draft for over a month, as he had wished to "read more deeply" on areas of the text "of which [he] never possessed more than a superficial knowledge so as to become better qualified to criticize" them.[27] A year later, when Somerville approached him with a query about a method of integration using indeterminate coefficients (to which we will return below), Herschel admitted that "I was once very familiar with this part of the mec cel. — and yet I always found some thing catching in the reasoning".[28] Moreover, he warned Somerville that there would be very large parts of her work that he could not pretend to be able to give an opinion.[29] Therefore, even Herschel, a founding member of the Cambridge Analytical Society who had graduated as Senior Wrangler from Cambridge in 1813, found difficulty in reading and digesting *Mécanique Céleste*. This speaks not only to the complexity of Somerville's task, but also the limited potential readership of such a work.

Alongside the letters flowing between Somerville in Chelsea and Herschel in Slough or central London, packets of manuscript pages were frequently exchanged. These manuscripts were often ferried by a 'Mr. Richards'; Richards could perhaps have been a mutual acquaintance of both Somerville and Herschel who frequently travelled between the two locations, as at one point he was described by Herschel as "our good friend", or an agent acting on behalf of Murray to ensure the smooth preparation of the work uninterrupted by manuscript pages getting lost en-route.[30] It appears that these manuscript pages are no longer extant, which is unfortunate as many of Herschel's criticisms and corrections were, according to him, in the form of pencil annotations.[31]

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27 HS/16/337.

28 HS/16/343.

29 MS, Dep. c. 370, MSH–3 301, John Herschel to Mary Somerville, undated.

30 HS/16/334. Richards is mentioned in HS/- 16/328, 16/329, 16/332, and 16/339. Richards' first name was never given, but it seems he was not a Fellow of the Royal Society, nor the Royal Astronomical Society. Later when living in Italy, Somerville's writing was often hindered by manuscript pages getting lost in the post. In October 1861 she sent a manuscript of what would become the fifth edition of *Physical Geography* via the British Embassy at Turin, and it took over two months to arrive and be liberated from the Foreign Office by Murray. NLS MS 41131, 137–143.

31 HS/16/329. According to the Bodleian catalogue, MS Dep. c. 351 Folder MSSW–1 contains a notebook with undated notes and comments in Mary's hand on *The Mechanism of the Heavens*, but owing to the archive closures caused by Covid-19 this material has not yet been consulted.

As well as proof-reading the manuscripts, Herschel offered advice to Somerville regarding the arrangement and selection of the material she chose to include in her translation. He suggested that she assume her reader already to possess a good knowledge of algebra and geometry, and to therefore remove statements of the more 'elementary' properties and methods she had given at the very beginning of Book 1.[32] As a convenient aid for referencing, Herschel suggested numbering the paragraphs. As can be seen in the published work, Somerville did introduce a numbering system of which she made extensive use, frequently referring the reader to other areas of *Mechanism*, for example when using the equation for equilibrium at a surface in article 239, she refers the reader back to article 69 in which this equation was derived (Somerville, 1831, p. 114).

From February to June 1830, there are 9 extant letters sent between John Herschel and Mary Somerville, suggesting a flurry of intense activity immediately after Somerville completed her first draft of the work. Within these letters specific aspects of the mathematical content were discussed.

Somerville specifically requested Herschel to look over her sheets on "La Grange's variation of Constant quantities".[33] The arbitrary constants here referred to are the properties of the planets' orbits which must be determined from astronomical observation. By considering these constants as variables, Lagrange was able to give expressions for all the perturbations in a planets' motion caused by a disturbing force, for example a gravitational attraction to a nearby planet (Galloway, 1832, p. 13). Herschel's reply indicates that he offered some minor amendments as annotations on the manuscript, and suggested that Somerville offer more guidance to the reader as to the "object of this curious analytical proof".[34]

In May 1830 after making the first round of revisions to the manuscript, Somerville sent it back to Herschel with the passages marked that she especially wanted him to read.[35] As can only be expected, Herschel occasionally had to bring an instance of careless work to Somerville's attention. For instance the following extract from the letter accompanying the new draft appears to have been motivated by Herschel pointing out a claim that the gravitational force between two bodies *increased* the further apart they were:

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32 HS/16/329.
33 HS/16/333.
34 HS/16/334.
35 HS/16/336.

Our heads are no longer in danger as I have used a counter
spell to keep the moon at a due distance. After so severe
a season I assure you I have no wish to pay her a visit,
far less to receive so cold a guest. I cannot understand by
what spell I made gravitation increase with the distance,
sure enough my computation was sadly careless.[36]

Twice, Herschel commented on Somerville's derivation of the general equation of the motion of a particle of matter:

$$\delta x\{Pdt - \frac{d^2x}{dt}\} + \delta y\{Qdt - \frac{d^2y}{dt}\} + \delta z\{Rdt - \frac{d^2z}{dt}\} - \lambda\delta u = 0. \quad (3)$$

The equation is first mentioned by Herschel in February 1830, where
he criticises Somerville on two counts.[37] He accuses her of assuming
the equation to be so, rather than showing it, and laments the omission of a demonstration showing the equivalence of the above general
equation to the following representation where the conditions of constraint are given separately:

$$\delta x\{Pdt - \frac{d^2x}{dt}\} + \delta y\{Qdt - \frac{d^2y}{dt}\} + \delta z\{Rdt - \frac{d^2z}{dt}\} = 0, \; u = 0. \quad (4)$$

A month later, Herschel wrote again, this time not just expressing
his dissatisfaction with Somerville's treatment of this fundamental
equation, but describing Laplace's own as "ingeniously obscure".[38]
Herschel subsequently gave a three page outline of what he found to
be a better way of proceeding; Somerville apparently agreed, as these
pages were reproduced in *Mechanism* almost verbatim (allowing for a
change of variables) without any attribution to Herschel (Somerville,
1831, pp. 21–25).

Many months later, in February 1831, the presses had to be stopped
so that Somerville could consult Herschel on her method of integration for the equations which governed the motion of the planets. The
urgency of this request is underscored by the handwritten postscript
written by Dr. William Somerville, in which he expressed his hope
that Herschel would accede to Somerville's solicitation.[39] Somerville
had doubts over her chosen method of integrating the following equation by the method of indeterminate coefficients:

$$\frac{d^2r\delta r}{dt^2} + n^2r\delta r = 2\int dR + r(\frac{dR}{dr}). \quad (5)$$

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36 HS/16/340, the letter is undated but must have been sent before May 1830, as it
   refers to Herschel having pages 50-133 of the manuscript in his possession, which
   he had not returned when Somerville penned letter HS/16/336.
37 HS/16/329.
38 HS/16/332.
39 HS/16/342.

This method was referred to by Somerville at least four times in *Mechanism*, but not once did she give an explanation as to what the method entailed, or how it worked (Somerville, 1831, pp. 16, 484, 511, 523). The greater difficulty in the application of the method in this instance, was that the general solution contained terms of the form

$$A \cdot nt \cdot \sin(nt + \epsilon - \omega)$$

where A, ϵ, ω, and n were constants, and t time. Somerville was unsure how to cancel these terms out — if they remained in the final solution then the terms would not converge to 0 as t became large, contradicting the stability of the solar system, and suggesting that the periodic orbits of the planets would eventually be destroyed. In her letter to Herschel, she attributes her treatment to Philippe Gustave Doulcet, Comte de Pontécoulant. It is highly likely that Somerville was here referring to his *Théorie analytique du système du monde*, the first two volumes of which were published in Paris in 1829, and, along with the third volume published in 1834, were part of Somerville's collection of books which were donated to Girton on her passing in 1872.[40]

Herschel's advice to Somerville was to abandon Pontécoulant's method if she had any doubts, and to instead "throw [her]self on the broad principles of Laplace as laid down in N° 43 of the second Book of the Mec. Cel., or as he has explained it rather more clearly... in the Mem Acad Sci 1772 p353 in a very beautiful memoir" (Laplace, 1772).[41] He provided for Somerville another three page outline of the method as he understood it; however, unlike before, this was not quoted verbatim by Somerville in *Mechanism*. Instead, Somerville omitted the technical details which enabled mathematicians to discard the problematic terms that were not periodic, giving her reader only a brief explanation as to the impossibility of such terms, and attributing their existence in the calculations to the imperfection of analysis. She invoked the authority of Herschel to strengthen her stance, and directed the interested reader to the sources he had suggested Somerville herself should read (Somerville, 1831, p. 314).

It is worth noting here that Laplace's treatment in number 43 of the second Book of *Mécanique Céleste* was far more general than was necessary for Somerville's integration of the equations of the motions of a planet (see equation 6). Whereas Somerville considered three simultaneous second order differential equations, Laplace looked at n

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40 Girton College Library: Somerville Collection (073180).
41 HS/16/343.

simultaneous differential equations all with order i.[42] Such a general treatment had no place in a work on physical astronomy which consistently referred all calculations back to concrete conclusions on the motions of the celestial bodies, and therefore certainly didn't consider the existence of more than three dimensions.

In both examples of difficulties discussed by Herschel and Somerville, the translation process involved removing material that was deemed unnecessarily general or obscure, and producing new content that would be tractable to the envisioned reader whilst maintaining the cogency of the work.

4.4 THE MATHEMATICS OF THE *mechanism*

Somerville spent another year refining her translation, which in around July 1831 was given the title *Mechanism of the Heavens*, after the suggestion of John Elliot Drinkwater Bethune (see section 3.5). In November 1831, the translation was finally published, to great critical, if not commercial, success.

Mechanism of the Heavens contained four Books, published as a single Volume, which covered: an introduction to dynamics, including central forces, rotation, the motions of a system of bodies, and basic fluid dynamics in Book 1; Book 2 applied this theory to the elliptical motions of the planets, with the motions of Jupiter and Saturn considered separately owing to their significantly greater mass compared to the other planets; Lunar theory was treated in Book 3 (that is, a consideration of Earth's only satellite); whilst the fourth and final Book considered the motions of the four satellites of Jupiter which were known at the time.

At the conclusion of Book 1 of *Mechanism of the Heavens*, Somerville explicitly noted that it formed her account of Book 1 of *Mécanique Céleste* (Somerville, 1831, p. 144). Somerville's Book 2 also roughly corresponded to Book 2 of *Mécanique Céleste*, except Chapters 10 to 14 in *Mechanism* gave brief overviews of Laplace's Book 6. On average, a chapter by Laplace was demolished in around two pages by Somerville. Somerville also included a few pages on methods of correcting errors in astronomical tables, which Laplace did not include

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42 In his review of *Mechanism*, Herschel noted that Laplace's derivation of the equations of elliptical motion was excessively general, and claimed it was useful only as a demonstration that the theory of elliptical motion had been "probed to the quick, and every resource which analysis could furnish exhausted on it", rather than as a method to be used in practice (Herschel, 1832, p. 554). He then complimented Somerville for her choice to replace the derivation with one by "direct integration", describing her chapters on the elliptical motion as concise and perspicuous.

until his final chapter of Book 10, Volume 4. Book 3 of *Mechanism* loosely corresponded to Book 7 of *Mécanique Céleste*, whilst Book 4 of *Mechanism* loosely corresponded to Book 8 of *Mécanique Céleste* but executed in half the number of pages.[43] Topics which were omitted by Somerville include a detailed treatment of attractions of ellipsoids, which enables an investigation of the shape of celestial bodies; the tides; the rings of Saturn; the theory of comets; and refraction of light through the atmosphere, which affects the observational data used in calculations when investigating the motions of celestial bodies. In his review of the book, Thomas Galloway, a teacher of mathematics at the Royal Military College, claimed that Somerville had "wisely selected that department of Physical Astronomy which, in consequence of the degree of perfection it has attained, is most likely to retain its present form" (Galloway, 1832, p. 25).

Preceding the account of Laplace's *Mécanique Céleste* was a sixty-six page Preliminary Dissertation written by Somerville. This dissertation motivated a mathematical study of the motions of the celestial bodies by summarising and describing the results which would be demonstrated in the main work.[44] Notably no mathematical symbols or equations were used by Somerville in the Preliminary Dissertation, but she strongly encouraged those even without a deep grasp of mathematics to persevere with reading the entire text:

> A complete acquaintance with Physical Astronomy can only be attained by those who are well versed in the higher branches of mathematical and mechanical science: such alone can appreciate the extreme beauty of the results, and of the means by which these results are obtained. Nevertheless a sufficient skill in analysis to follow the general outline, to see the mutual dependence of the different parts of the system, and to comprehend by what means some of the most extraordinary conclusions have been arrived at, is within the reach of many who shrink from the task, appalled by difficulties, which perhaps are not more formidable than those incident to the study of the elements of every branch of knowledge, and possibly overrating them by not making a sufficient distinction between the degree of mathematical acquirement necessary for making discoveries, and that which is requisite for

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43 Somerville's four Books do not, therefore correspond to the first four Books of *Mécanique Céleste* as has been claimed (Patterson, 1983, p. 72).

44 For more on rhetoric and narrative devices used in the Preliminary Dissertation see (Neeley, 2001).

understanding what others have done (Somerville, 1831,
p. vii).

In her introduction, Somerville claimed that she did not intend
to "limit [her] account of the *Mécanique Céleste* to a detail of results,
but rather to endeavour to explain the methods by which these re-
sults are deduced from one general equation of the motion of mat-
ter" (Somerville, 1831, p. 3). These explanations appear to have been
aimed at readers with a strong mathematical background, but with
little knowledge of dynamics or the solar system. The first Book acted
as an introduction to the reader, presenting the methods which were
used to study the celestial motions, including the composition of
forces, the principle of equilibrium, the general equations of motion,
and the motions of systems of bodies. Crucially, the *mathematical*
knowledge which underpins these theories was given no treatment,
and I will here give an overview of the knowledge that Somerville
assumed of her reader.

At a basic level, Somerville certainly assumed her reader had stud-
ied geometry, especially conics, which was essential when studying
the elliptical motions of the planets. Very early on she introduced di-
agrams of circular, later elliptical, orbits from which she expected the
reader to be able to read off angles as well as projections onto a fixed
plane. The reader was furthermore expected to be able to recognise
the general equation of a conic in polar coordinates on sight, namely
$r = \frac{a(1-e^2)}{1-e\cos(v-\omega)}$, where the origin of the radius vector r is in one of
the foci, a is half the greater axis, and $v - \omega$ is the angle between the
body in motion, m, and the perihelion of its orbit (where the perihe-
lion, P on figure 18, is the point in the orbit of m closest to the Sun, S)
(Somerville, 1831, pp. 155, 193).

A basic knowledge of algebra and the theory of equations was
assumed, for example where Somerville stated without explanation
that a cubic equation in one variable has at least one real root (Somerville,
1831, p. 88).

Concepts from trigonometry were also used throughout the work,
without explanation. Beyond a geometrical understanding of the sine,
cosine, or tangent of an angle, for example using $\sin(\theta) = \frac{\text{opposite}}{\text{hypotenuse}}$
when calculating the force of gravitation on the moon, Somerville also
expected her reader to have an *algebraic* understanding of these prop-
erties (Somerville, 1831, p. 164). Notably she represented sin and cos
algebraically both as infinite series and in terms of c, whose natural
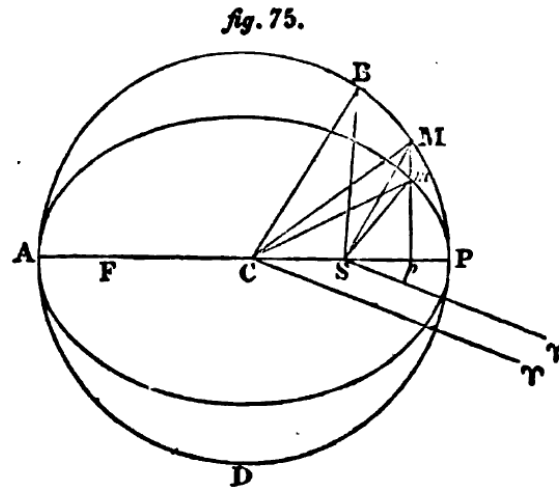logarithm was taken to be 1 (nowadays this number is usually rep-

Figure 18: Figure 75 from *Mechanism of the Heavens*, showing the elliptical orbit of m, and used by Somerville to show the six arbitrary constants which determine its orbit.

resented by $e = 2.71828...$) (Somerville, 1831, pp. 40, 119). This latter representation,

$$\sin mu = \frac{c^{mu\sqrt{-1}} - c^{-mu\sqrt{-1}}}{2\sqrt{-1}}$$

also relied on an understanding of complex numbers and natural logarithms, again neither of which were treated by Somerville (Somerville, 1831, p. 200).[45] Many of the algebraic manipulations carried out in order to simplify expressions involved the use of the compound angle formulae for the sine, cosine, or tangent of an angle, and the series representations were used to approximate $\sin \theta$ and $\cos \theta$ when θ was "very small" (Somerville, 1831, p. 133).[46]

In order to investigate the motions of the celestial bodies, such as planets and moons, Somerville introduced and explained the laws of dynamics, whereby she deduced differential equations which allowed the calculation of an orbit. For example, the equations which

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[45] Somerville moved between using the names 'hyperbolic logarithm' (Somerville, 1831, pp. 40, 244, 271), 'Naperian logarithm' (Somerville, 1831, p. 103) and just 'logarithm' (Somerville, 1831, pp. 140, 200) for logarithms with 'c' as their base.

[46] Compound angle formulae are standard results in trigonometry as follows: For angles θ_1, θ_2,

$$\sin(\theta_1 + \theta_2) = \sin(\theta_1)\cos(\theta_2) + \cos(\theta_1)\sin(\theta_2),$$

$$\cos(\theta_1 + \theta_2) = \cos(\theta_1)\cos(\theta_2) - \sin(\theta_1)\sin(\theta_2)$$

and

$$\tan(\theta_1 + \theta_2) = \frac{\tan(\theta_1) + \tan(\theta_2)}{1 - \tan(\theta_1)\tan(\theta_2)}.$$

described "the undisturbed elliptical motion of one body round the sun" were:

$$\frac{d^2x}{dt^2} + \frac{\mu x}{r^3} = 0$$
$$\frac{d^2y}{dt^2} + \frac{\mu y}{r^3} = 0 \qquad (6)$$
$$\frac{d^2z}{dt^2} + \frac{\mu z}{r^3} = 0,$$

where μ is the the mass of the sun added to the mass of the orbiting body, and $r = \sqrt{x^2 + y^2 + z^2}$ (Somerville, 1831, p. 184). To find x, y, and z (the coordinates of the orbiting body) it is necessary to integrate these simultaneous second-order differential equations. Although Somerville briefly explained the method by which she integrated these equations, which was attributed to Pontécoulant, she nevertheless assumed that the reader already had experience with integration; she stated as unequivocal fact that three linear differential equations of second order would give rise to six constants of integration, and once the equation was in the form of a complete differential, she executed the integration step without any intermediary explanation. No where in *Mechanism of the Heavens* was an introduction to the differential or integral calculus offered, and the reader was only once referred to such a text, in Chapter 2, Book 1 when Somerville quoted a standard result from "La Croix's *Integral Calculus*" (Lacroix, 1797–1800).[47] Somerville gave no general methods for solving differential equations, and she expected the reader to be familiar with the process of changing the variable of integration, and with the method of integration by parts (see section 2.4) (Somerville, 1831, pp. 180, 321). Moreover, there was no introduction to the theory of partial differences. It was merely referred to by Somerville in order to justify her conclusion that a multivariate function, when integrated with respect to one of the variables on which it depends, will give rise to a multivariate function which is independent of the variable of integration (Somerville, 1831, p. 136).[48]

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47 The result quoted is: $\int \frac{-dx}{\sqrt{\beta x - x^2}} = \pi; \int \frac{-x\,dx}{\sqrt{\beta x - x^2}} = \frac{1}{2}\beta\pi; \int \frac{-x^2\,dx}{\sqrt{\beta x - x^2}} = \frac{1}{2} \cdot \frac{3}{4}\beta^2\pi$ (Somerville, 1831, p. 46). As Somerville referred to this text only as Lacroix's 'Integral Calculus' she was most likely referring to the original French edition of his *Traité du calcul différentiel et du calcul intégral* — printed in three volumes, with the first treating differentiation, the second integration, and the third differences and series — rather than the Analytical Society's later translation which appeared as a single volume (Lacroix, 1816).

48 When a function depends on two or more variables, say x and y, a partial difference is the difference taken with respect to one variable, the other(s) assumed to be constant.
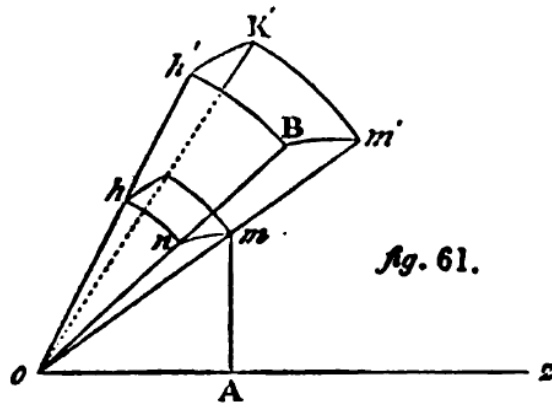
Figure 19: Figure 61 from *Mechanism of the Heavens*, showing the rotation of $Bnhh'$, a rectangle of fluid mass, rotating about the axis oz.

As discussed above, algebra applied to trigonometry, solving differential (or fluxional) equations of all orders, and the theory of partial differences, were all important recent developments in mathematics that were essential to the study of physical astronomy (Playfair, 1808). Playfair also listed the calculus of variations, which receives only a brief 1-page description from Somerville. The only development mentioned by Playfair that got a *mathematical* treatment by Somerville was the principle of equilibrium, which she showed how to express 'analytically' in her first chapter of Book 1.

As would be expected from Somerville's early adoption of differential notation and language in her mathematical practice, fluxions were not used in *Mechanism of the Heavens*. Unlike Toplis, Somerville felt no need to justify her inclusion of "infinitesimally small" objects, and in fact made use of infinitesimals throughout the book with very little reflection. When investigating the continuity of a fluid, Somerville considered a rectangular portion of fluid mass, $Bnhh'$, as it rotated about the axis oz (see figure 19) (Somerville, 1831, p. 131). She let the radius oB be represented by r, and the radius on by r', then claimed that as the thickness of the rectangle of fluid was 'indefinitely small', then

$$r' + r = 2r$$

and

$$r' - r = dr.$$

This created an obvious contradiction. The first equation implies that $r' = r$ and substituting this into the second gives that $dr = 0$. Somerville manipulated dr as a non-zero quantity, most clearly when dr appeared in the denominator of a term in the equation of

the continuity of a fluid; dividing by zero being, of course, not well-defined.

An understanding of terms being small enough to be neglected in some situations, but not in others, was used throughout *Mechanism of the Heavens*. Although a concept of limits was not used explicitly, and certainly not in a way that could be described as rigorously, Somerville frequently made recourse to the 'order' of an object to justify neglecting terms of 'higher order' when approximating infinite series. Again, there was no reflection or discussion on the theory of infinite series — when can terms be neglected? How quickly do the series converge, if at all?[49] Somerville made use of numerous standard results, such as Taylor's theorem and subsequently Maclaurin's theorem to find the series expansion of a function in terms of its differentials (Somerville, 1831, pp. 139, 197), and the Binomial Theorem when representing $(a'^2 - 2aa' \cos \beta + a^2)^{-\frac{1}{2}}$ as an infinite series (Somerville, 1831, p. 236). These theorems were cited without proof nor demonstration, nor suggestions of where the reader could learn more if they were unfamiliar with the mathematics.

Although Somerville did not explicitly mention a decline in British mathematics in *Mechanism of the Heavens*, she did actively advocate for analytical mathematics throughout. She demonstrated the power of analysis as a tool to uncover information which couldn't possibly be observed by astronomical observation alone, for example irregularities in the motions of planets which were too small to be observed by even the most powerful telescopes, or which took place over millennia and so couldn't be traced by the mortal astronomer.

In her history of the progress of astronomy, Book 2 Chapter 1, she opined that "had not the improvements in analysis kept pace with the rapid advance in astronomy" it would have been impossible for Laplace to form "a complete system of physical astronomy" where the irregularities in the motions of the bodies in the solar system were all accounted for by the gravitational pull between the bodies themselves (Somerville, 1831, p. 150). She also quoted directly from the letter written to her by Laplace in 1824, where he praised the elegance of the synthetic methods by which Newton demonstrated his discoveries in his *Principia*. These discoveries formed the basis of Laplace's *Mécanique Céleste*, but he was convinced of the indispensable necessity of analysis to tackle the most difficult questions in physical astronomy. Laplace recognised the mathematicians in Britain who were then beginning to adopt analysis, which suggests an increasing international visibility of the reform community, and expressed his

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49 Somerville was aware of different rates of convergence, see (Somerville, 1831, p. 236).

confidence that, should such mathematicians pursue analysis with their usual sagacity, then important discoveries would surely follow (Somerville, 1831, p. 150). It is clear from the inclusion of this letter extract, and the many places where Somerville highlighted areas in which further research was required to extend approximations to higher degrees of accuracy, that she intended *Mechanism* as a work to encourage British mathematicians to join the ranks of those who adopted and developed analytical methods.

In summary, whilst *Mechanism of the Heavens* certainly brought analytical mathematics, and its applications to Physical Astronomy, to the attention of more readers it was by no means a book designed for those beginning to study this mathematics from scratch. The physical laws, and the ways in which they were modelled and investigated, were treated in depth, but Somerville made extensive use of advanced theorems and methods without offering explanations or proofs, or directing the reader to where these could be found. Therefore it is untenable to describe the work as a popularisation of the *mathematics* used by Laplace in his *Mécanique Céleste*.

4.5   A BOOK FOR BLUESTOCKINGS OR WRANGLERS?

Within three months of the publication of *Mechanism of the Heavens* in November 1831, at least five reviews appeared: in the *Literary Gazette*; the *Monthly Review*; the *Athenaeum*; an article by Biot in the *Journal des savans*; and a one-page announcement in the *Monthly Notices of the Royal Astronomical Society*. More substantial reviews were subsequently published in the *Edinburgh Review* in April and the *Quarterly Review* in July of 1832.[50] Notice of the work was also taken by Adolphe Quetelet in Belgium, who wrote a brief announcement of the work in his journal *Correspondance Mathematique et Physique* (Quetelet, 1832). Overall the reviews were very favourable and, as discussed in the introduction to chapter 3, Somerville was recognised for this work with honorary memberships of multiple learned societies.

A number of the reviewers saw the importance of the work as a partial remedy to the decline of mathematics in Britain, and drew a direct line from the works of Newton, his *Principia* and fluxional calculus, to Somerville. One review claimed that the principal aim of Somerville was not to translate Laplace but to give an explanation of the extremely difficult problems in applying Newton's law of gravitation to the motions of the planets; Newton's law of gravitation was described as the "great foundation of our acquaintance with the heav-

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50   Facsimiles of each review can be found in (Secord, 2004, Vol 1).

ens", whereas Laplace's *Mécanique Céleste* was only noted as a text Somerville relied on when preparing her explanation (Anon, 1832a, p. 137). Writing for the *Quarterly Review*, John Herschel lamented the lack of British contributions to the study of physical astronomy;

> as if content with the glory of originating it, and dazzled and spellbound by the first great achievement of Newton, his countrymen, with few and small exceptions, have stood aloof from the great work of pursuing into its remote details the general principle [gravitation] established by him (Herschel, 1832, p. 541).

That the country which had produced Newton had allowed his work to stagnate on their own shores, and was now indebted to 'foreigners' for developing the work to its current perfection was seen as a source of shame. It was thus the responsibility of mathematicians to reclaim the work of Newton. Indeed, in the *Literary Gazette* Somerville's role was described as "the energetic and public-spirited interpreter between the great continental successor of Newton, and the less instructed mathematicians and astronomers of her native country" (Anon, 1831, p. 1). The Council for the Royal Astronomical Society expressed their wish that Somerville's example would encourage others to exertion in this field which they felt had "been too much neglected in England" (Anon, 1832b).

Framing *Mechanism* as a public service, rather than a contribution to mathematical knowledge, was often used to justify Somerville's authority as a woman to author such a text. In his review of the work, Biot felt it necessary to begin by reassuring the reader that Somerville was inspired by a desire to be useful, and did not aim for personal glory. He then spent a page justifying why Somerville had the authority to produce a translation of Laplace, including an extensive quote from Fontenelle in which he discussed the female 'disciples' of French mathematician Louis Carré, who were valued for their philosophical knowledge, which spoke to the intellectual capacities of women in general.[51] Similarly the reviews in both the *Monthly Review* and the *Edinburgh Review* began with discussions on the history of scientific women which lasted for multiple pages. As quoted above, the *Literary Gazette* described Somerville as "public-spirited" for acting as an interpreter between Laplace and British mathematicians, whilst Galloway gave her the title of "benefactor of science" for her contributions to making the analytical mathematics underpinning physical astronomy more easily understood (Galloway, 1832,

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51 Louis Carré (1663–1711), and Bernard le Bovier de Fontenelle (1657–1757).

p. 3). The *Monthly Review* saw it as a matter "worthy of national congratulations, that a lady of extraordinary talents... should enlist in the ranks of the missionaries of 'useful knowledge'" (Anon, 1832a, p. 140). Moreover, focusing on the utility of *Mechanism* for the general public fitted the work into a tradition of female-authored pedagogical scientific texts, even if it was ultimately intractable to such readers (Peters, 2017).

By framing *Mechanism* as a philanthropic act, the book furthermore served to support rather than undermine Somerville's image as a gentlewoman. She was celebrated as proof that women "labour unjustly under a prejudice that would assign a superior intellect to man", and that intellectual pursuits were commensurable with the "ordinary duties" of society ladies — Biot was even more explicit about what these ordinary duties were, describing Somerville as gifted with all of the favours of a woman who, despite her serious studies of the highest sciences, remained a gentle woman, a good wife, and an excellent mother (Anon, 1832a), (Biot, 1832, p. 28).

Before investigating the reviewers' opinions on the mathematical content of *Mechanism*, it is worth considering the mathematical background of the reviewers themselves. Whilst all but the review by Biot were published anonymously, Patterson identified Galloway and Herschel as the reviewers for the *Edinburgh Review* and the *Quarterly Review* respectively (Patterson, 1983, p. 85). Patterson also conjectured that the author of the *Athenaeum* review was Charles Buller, a barrister and Member of Parliament who, according to Somerville, made derogatory remarks about the book in the House of Commons and in 1837 argued against her civil list pension (Patterson, 1983, pp. 83–84, 161).[52]

Galloway was born in 1796 and grew up as the son of a tenant farmer in Lanarkshire, Scotland. In 1811 he made the acquaintance of French military officers, prisoners of war on parole, who gave him mathematical instruction. A year later he began his studies at the University of Edinburgh, but seems not to have taken much interest in the mathematics curriculum there. Like Somerville, in 1815 he began corresponding with William Wallace, and like Somerville was awarded a prize for his solutions to mathematics puzzles. However, unlike Somerville, Galloway was appointed a teacher of mathematics at the Royal Military College where he was working at the time he

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52 City University of London holds a collection of the *Athenaeum* with reviewers' names in the editor's hand, but unfortunately the volume from 1832 does not include editor's marks so I was unable to confirm authorship at this time. With thanks to Andrew Medder, Librarian who consulted the archive on my behalf during library closures caused by Covid-19.

wrote his review, and was elected a fellow of the Royal Astronomical Society in 1828. Galloway wrote numerous mathematical papers, including many articles in the *Encyclopaedia Britannica* which gave treatments of work by Laplace and Poisson (Anon, 1852). The strong mathematical backgrounds of John Herschel and Jean-Baptiste Biot have already been mentioned, and the reviewer writing for the Royal Astronomical Society can be assumed to have been at least interested in mathematics and physical astronomy by virtue of their membership of and engagement with the society.

There is little evidence for the mathematical competencies of the other reviewers. In fact, the reviewer for the *Monthly Review* openly admitted that the "purely algebraical character" of Somerville's explanations, and the number of diagrams used placed the "course of reasoning" beyond their powers. Charles Buller, conjectured to be the author of the *Athenaeum* review, had graduated from Cambridge in 1828 with a Bachelor of Arts. He became an MP in 1830, and was called to the bar in 1831; he was simultaneously an active politician, barrister, and contributing author to numerous magazines and reviews (Spencer, 2008).[53] The reviewer for the *Literary Gazette* avoided giving an account of *Mécanique Céleste* citing a lack of time and an aversion to shocking the reader with an onslaught of symbols, but assured the reader that they, of course, had the necessary knowledge to do so were they "disposed to shew off [their] learning" (Anon, 1831). It seems very unlikely, however, that the author was capable of making informed criticisms of the mathematics at hand, as the review itself focused almost exclusively on Somerville's *Preliminary Dissertation*, which, whilst full of technical language, contained no mathematical demonstrations or explanations.

This focus on the *Preliminary Dissertation* was used to support the reviewer in their argument that the *Mechanism of the Heavens* in its entirety served to condense and popularise the mathematics of Laplace and its applications to physical astronomy. As has been seen, one of the most important tasks of the translators of Laplace was seen to be to render the mathematics more accessible in general, and especially to a reader unfamiliar with the mathematical practice of France.

One of the main ways in which Somerville consciously offered assistance to her reader was the introduction of diagrams. Laplace did not use diagrams in his own work as at the time they were felt to be unnecessary in analytical works (Somerville, 1831, p. 3).[54] Somerville

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53 Buller was a staunch advocate for electoral reform in the UK, and shared the mutual acquaintance of John Stuart Mill with Mary Somerville.

54 As is well-known, at the beginning of his *Mécanique Analytique* Lagrange declared that the reader would find no figures in the work, as the methods he used did not

included 116 diagrams in *Mechanism*, over half of which appeared in Book 1. They served a variety of purposes including: displaying the physical system that was being investigated — such as a compound pendulum (Somerville, 1831, p. 107); defining technical terms like conjunction or syzigies (Somerville, 1831, pp. 416, 467); or the depiction of solutions of systems of differential equations (Somerville, 1831, pp. 274–278).[55] Where Somerville chose to omit the technical details of a proof, she occasionally provided a diagram and brief explanation to enable the reader to form "some idea" of how the proof would proceed (Somerville, 1831, p. 479). According to Galloway, the diagrams did not touch on the real difficulties of the work, and in fact could serve to fatigue and distract readers as they were unnecessary to the chain of evidence in the mathematical arguments.

Moreover, the accessibility of *Mechanism of the Heavens* to readers without highly advanced mathematical literacy was sharply criticised by Galloway, and to a lesser extent by Herschel, the two most mathematically competent reviewers of the work. As was discussed in the previous section, Somerville assumed a high level of mathematical content in her reader and Galloway claimed that "in order to comprehend fully the 'Mechanism of the Heavens' little, very little, abatement can be made from the amount of mathematical knowledge which is indispensably required to enter with advantage or profit on the study of Laplace" (Galloway, 1832, p. 5). Indeed, when critiquing Somerville's treatment of Jupiter's satellites (in Book 4) Galloway expected that a student would find Somerville's condensed explanations of the analytical operations *more* difficult to master than those given in *Mécanique Céleste* itself (Galloway, 1832, p. 24). The greatest fault Herschel found in Somerville's work was "an habitual laxity of language" which, for the reader "less intimately conversant with the actual analytical operations than its author … must have infallibly become a source of serious errors".

Somerville herself offered no reflection on where and why she replaced the methods given by Laplace in *Mécanique Céleste*, or indeed why sometimes she offered multiple methods to reach the same result. This lack of reflection was underscored by Galloway as the greatest fault of the work, citing mostly pedagogical reasons. He noted that by giving two methods, the student would rightly wonder why a second method was necessary —- what are the limitations of the first, what

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require constructions or geometric reasoning, but rather algebraic operations alone (Lagrange, 1788, p. vi).

55 (Tournès, 2012) treats the usage of diagrams in works on differential equations in the eighteenth and nineteenth centuries.

are the strengths of the second, and in which situations should one be employed rather than the other? The reader was "hurried into the midst of an intricate investigation, the uses and object of which he is left to infer, as well as he can", making the work more discouraging and less instructive than it might otherwise have been (Galloway, 1832, p. 18). A similar critique was raised by Herschel when he reviewed Somerville's sheets on the variation of arbitrary constants before publication (see above) as his only advice was to include more information for the reader about the aims of a somewhat unintuitive proof. Without these reflections, a student might be able to persevere and memorise the many methods showcased, but would gain little understanding or intuition for how to proceed when applying the methods in their own investigations.

In her *Recollections* Somerville remarked that the "highest honour [she] ever received" was her book being introduced into the course of studies at Cambridge University by Peacock and Whewell, who were then fellows at Trinity College (Somerville and Somerville, 1873, p. 172). Moreover, Whewell positioned his own subsequent book on dynamics as a sort of introduction to "books of instruction for the higher parts of [mechanics]", one of which being Somerville's *Mechanism* (Whewell, 1832, p. v). However, it is unclear to what extent her book was read or used by students. Peacock described it as an essential work only for those students who "aspire[d] to the highest places" in the Tripos, and already by the 1830s the influence of private tutors outweighed that of tutorial fellows on the direction of students' studies (Warwick, 2001). Adam Sedgwick, a geologist who graduated as 5th Wrangler from the University of Cambridge in 1808, was recorded by Charles Lyell in his journal entry for 2nd February 1832 as saying that few men at Cambridge could go far enough to even begin reading *Mechanism* (Lyell, 1881, p. 368). Lyell himself saw the manuscripts of *Mechanism* before publication, and of the 700 pages of the work, he estimated that "about 500 pages [were] algebraic, x, y, z and sealed save to those deeply initiated" although he trusted that "the introductory 100 [would] be popular and serve as sails and winds to waft the heavy cargo on through unpromising times" (Lyell, 1881, p. 324).

Biot saw Somerville's choice to retain the mathematical calculations in her treatment of physical astronomy as a conscious choice. According to him the task given to Somerville, to write a popular account of physical astronomy, was impossible. Ideas which relied on the "the language of calculus" could not possibly be explained clearly and precisely without it, giving as an example the stability of the solar system — arguably the most important result in physical astronomy — whose

truth and certainty could only be understood through inspection of the algebraic symbols, which most efficiently presented to the eye of the mathematician all the necessary relations which must be considered. Biot felt that "Mrs. Somerville [had] studied the great truths of celestial mechanics too deeply... to resolve to denature and mutilate them" by presenting them without the calculus on which they were founded (Biot, 1832, p. 30).[56] Galloway also recognised the enormity of the task of rendering the mathematical reasoning legible to a general readership, stating that "however numerous the explanations may be, they can never supersede the necessity of a very extensive acquaintance with the abstract theories of pure mathematics" (Herschel, 1832, p. 5).

The interest and benefits for the general or mathematical untrained reader lay not in the mathematical reasoning, but in the information about the solar system gleaned from such reasoning. In the *Monthly Review*, immediately after the passage quoted above in which the author admitted that the mathematics was beyond their comprehension, they reaffirmed that the interest of the general reader would nonetheless be excited by "curious observations" and "important facts" placed frequently throughout the work (Anon, 1832a, p. 137). That is, throughout *Mechanism* Somerville summarised for the non-mathematical reader in a clear and informative manner what could be deduced from the preceding mathematics. For example, in chapter 3 of Book 3, Somerville began by determining a value for the compression of the Earth using multiple formulae for the perturbations of the motion of the moon which had been introduced in earlier chapters, and substituting in astronomical data. This was then compared to what the compression of the Earth would be if it were homogeneous (of a constant density). The two values for the compression of the Earth clearly differed, and even readers who could not follow the mathematical reasoning or keep pace with the astronomical jargon could comprehend the final conclusion: the path taken by the moon in its orbit proved that the Earth was of a variable density. That knowledge about the internal structure of the Earth could be deduced from the moon's orbit was described by Somerville as "a singular instance of the power of analysis", which was consistent with her intention to advocate for the importance and utility of analytical mathematics through the work (Somerville, 1831, p. 477). Nevertheless, the *Athenaeum* reviewer

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56 "Mme Sommerville avait étudié trop réellement les grandes vérités de la physique céleste... pour se résoudre à les dénaturer et à les mutiler." Translation my own. Biot used 'géomètre', which is here translated as mathematician.

opined that "the work laugh[ed] all simplicity to scorn..." (Anon, 1832c, pp. 2–3).

Therefore, as was argued in the previous section, *Mechanism of the Heavens* may have served as a 'popular' physical astronomy text, bringing knowledge of the applications of analysis to the celestial movements to a wider readership, but was entirely insufficient as a text by which beginners could enter into a study of the mathematics itself.

A question remains — how useful was the text to those who *were* literate in mathematical analysis, and the community of reformers of British mathematics of which Somerville was a part?

As alluded to above, nearly thirty years had passed since the publication of the first four volumes of *Mécanique Céleste*, during which time mathematical research had not stood still, on either side of the channel. Galloway identified multiple areas where "ample scope [would] always remain for the exercise of the most inventive talent", namely "in the finite integration of formulae that have hitherto been found intractable; in the investigation of series that converge more rapidly; in the reduction of difficulties to classes, and [in] rendering the methods already known more simple and uniform" (Galloway, 1832, p. 3).

When in 1830 Somerville received from Herschel a copy of Nathaniel Bowditch's recent translation of *Mécanique Céleste* she immediately recognised the differences between his project and her own, replying to Herschel:

> Nothing can be kinder than your early communication of the translation of the Mec. Cel. I have gone through the commentary as far as the time as permitted and excellent as the notes are, I confess I am not dismayed as I rather wish to state principles clearly, and to arrive at the results by as easy methods as possible, than to enter into all the mathematical detail.[57]

Whereas Bowditch used extensive footnotes (see figure 17) to guide the reader through each step of Laplace's workings, Somerville embedded her new material directly into the text to produce a single cohesive narrative. Whilst she intended to maintain what she described as the "spirit of Laplace" in her work, these additions certainly included methods and content from other authors who had since developed and built upon his work (Somerville, 1831, p. 3). Although Somerville rarely gave explicit references, she did occasionally attribute a method or a demonstration to a particular author.

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57 HS/16/333.

By name, she mentioned: Jean-Baptiste Biot; Marie-Charles-Théodore de Damoiseau; Philippe Gustave le Doulcet, Comte de Pontécoulant; Joseph-Louis Lagrange; Adrien-Marie Legendre; John Lubbock; Tobias Meyer; Jean Plana; Simeon-Denis Poisson; Johann Andreas von Segner; Robert Woodhouse; as well as numerous astronomers and natural philosophers when discussing their observational and experimental results.[58]

Somerville only mentioned Pontécoulant twice throughout the work, but Galloway proposed that she relied heavily on his *Théorie analytique du système du monde* (Pontécoulant, 1829-1846). As we saw above, it is very likely that Somerville did have access to the first two volumes by March 1831, when she discussed the method of indeterminate coefficients with Herschel. In the opinion of Galloway, it was Pontécoulant who amalgamated the methods of Lagrange and Poisson to bring greater lucidity to the theory of the 'variation of arbitrary constants', and Somerville "judiciously availed herself of [his] labours" (Galloway, 1832, p. 13).[59] Galloway noted that Somerville's demonstration of the formulae for calculating the perturbation of a planet m by a second planet m', using this theory, is identical to that of Pontécoulant even though she does not attribute it to him, nor did she mention his work when asking Herschel to review her sheets on this subject (see above). Perhaps in an attempt to justify Somerville's use of this demonstration rather than the one given by Laplace, Galloway noted that they are "in principle" the same, with the former being considerably simpler (Galloway, 1832, p. 14). Two other instances were identified by Galloway where Somerville used a demonstration as given by Pontécoulant, namely her treatment of the rotation of a solid body in Book 1, Chapter 5, and the method of determining periodic inequalities in the orbit of a planet in Book 2, Chapters 7 and 8.[60] It is worth noting here that a common practice of explicitly and assiduously referencing sources in mathematical texts was only just emerging — indeed in Volume 1 of his translation alone, Bowditch introduced twenty references in his footnotes which had been omitted by Laplace (Preveraud, 2015, p. 28). Galloway's discussion on Somerville's use of Pontécoulant was not a negative critique,

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58 This list matches relatively well to the names given by the reviewers when discussing those whose work Somerville had made use of, with Herschel lamenting only the omission of any treatment of comets, and therefore the work of Carl Friedrich Gauss and Johann Heinrich Lambert.

59 The arbitrary constants arise in the calculations as the six constants of integration when integrating equations 6 (Somerville, 1831, pp. 183, 193).

60 The periodic inequalities of an orbit are the inequalities which return to the same values at regular intervals (Somerville, 1831, p. 214).

but rather an approbation on her deft use of the most recent work in physical astronomy to present her reader with the simplest or most lucid demonstrations.

That Somerville took it upon herself to amend and update the work of Laplace was not, however, universally praised. The reviewer for the *Athenaeum* expressed their horror at the "sacrilege of remodelling the thoughts of La Place" committed by Somerville, as Laplace was "perfectly competent to convey his meaning in his own words... and it is our religious belief that any person capable of *understanding* (we use the word emphatically) the mechanism of the heavens at all, will understand it best in his own pages" (Anon, 1832c).

As well as ensuring that flattering reviews of *Mechanism* appeared promptly in the *Quarterly* and *Monthly* Reviews, Somerville circulated copies throughout her network of scientific correspondents to try and ensure that it was widely read. Through Charles Lyell and Leonard Horner a copy was sent to the Professor of Mathematics at the University of Bonn, Julius Plücker (1801–1868), whilst Somerville sent a copy directly to Georges Cuvier in Paris whom she had met in 1817 (Patterson, 1983, pp. 87–88).[61] Although she did not attend herself, copies of *Mechanism* were certainly making the rounds at the British Association for the Advancement of Science meeting in York in 1831, as a copy passed from David Brewster, to Charlotte Murchison, to her husband Roderick Murchison who wrote to Somerville to thank her for "this most valuable present".[62] Copies were also gifted to the Royal Society of London, the Philosophical Society of Cambridge, Trinity College, Cambridge, and, as we saw in section 3.3, the Société de Physique et d'Histoire Naturelle de Genève.[63]

Once these copies arrived in their respective libraries and private homes, it is unclear how often and by whom they were read. The copy in the Royal Society of London was taken out only three times before 1837 by fellows John Bostock (1773 - 1846), Sir Francis Palgrave (1788–1861), and William Ritchie (c.1790-–1837), all in 1832.[64] In January of that year, Somerville sent a copy of *Mechanism* to James Ivory, who was "somewhat astonished to receive a book treating of so many

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61 MS Dep. c. 371, MSP–4 274, Julius Plücker to Leonard Horner, 11/01/1832. The metadata of the Cuvier letter was sourced from Calames, the online catalogue of archives and manuscripts in French University and Research Libraries at http://www.calames.abes.fr/pub/ms/Calames-2015111616113213494 on 16/05/2021: Manuscrits de la Bibliothèque de l'Institut de France, Ms 3253-3255 / Ms 3254 / f. 192-193, 02/05/1832.

62 MS Dep. c. 271, MSM–5 216, Roderick Murchison to Mary Somerville, 10/1831.

63 On the receipt of *Mechanism*, Adam Sedgwick proposed Somerville as a member of the Cambridge Philosophical Society but was unsuccessful (Patterson, 1983, p. 88).

64 RS MS/401/2.

difficult and abstruse subjects, written by a Lady with so much clearness and method".[65] Although he waxed lyrical about his views on the development of physical astronomy, Ivory admitted he had not yet had time to peruse her work carefully, and hoped he could do himself the honour of calling on her personally once he had done so. Similarly, Somerville's old mentor and previous colleague of Ivory, William Wallace, wrote to Somerville in December to thank her for his copy of *Mechanism* and congratulate her on her bold feat which rendered an important service to science, even though the closest he had gotten to reading the book was to place it on his table with sincere intentions of opening it.[66]

The perceived importance of *Mechanism* was as a symbol, demonstrating Somerville's mastery of Laplace's work as an auto-didact who retained her femininity and respectability (Secord, 2014). To appreciate her mastery, it was not required to trudge through the mathematics but could be taken on the faith of the expert reviewers: the RAS review described Somerville's work as "the most complete account of the discoveries of continental mathematicians in physical astronomy" which existed in English, whilst Herschel opined that he knew "not the geometer in this country who might not reasonably congratulate himself on the execution of such a work" (Anon, 1832b), (Herschel, 1832, p. 548). The community of people who would actively benefit from reading *Mechanism* was, as with most advanced scientific texts, far too small to expect it to become a bestseller. Moreover if a reader wanted to emulate Somerville's feat as an auto-didact, then *Mechanism* was not the book to start with. Without first studying mathematics to a high level the reader would walk away with a series of grand conclusions about the motions of the celestial bodies and only little understanding of how they were reached. Perhaps the *Athenaeum* reviewer was not too far off the mark when they imagined *Mechanism* "reposing in graceful indolence on the table of every confirmed blue of the United Kingdom... what a world of delightful prattle it will originate!" (Anon, 1832c, pp. 2–3).

4.6   CONCLUSION

Mechanism of the Heavens is by far Somerville's crowning achievement as a mathematician. Producing a translation of such a work would have been impossible without an expansive knowledge of mathematical literature, produced in both Britain and continental Europe, and

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65 MS Dep. c. 371 MSI–1 1, James Ivory to Mary Somerville, 03/01/1832

66 MS, Dep c. 372, Folder MSW–1 and see Appendix B.

Somerville would not have been commissioned and supported to write such a work had she not so deftly carved her place within a mathematical community. Transplanting *Mécanique Céleste* from France to Britain required work in multiple domains, including the linguistic, the cultural and the mathematical. It was a mammoth task to condense five volumes into one, whilst also introducing extensive explanatory materials and embedding Laplace's methods into a foreign mathematical practice.

It is difficult to ascertain who Somerville's intended audience was for her translation. Although it was originally commissioned by the Society for the Diffusion of Useful Knowledge, the level of mathematical knowledge assumed in the reader was far above what could have been expected of the readership of the SDUK. In fact, Somerville assumed the very mathematical knowledge in her reader that John Playfair had previously identified as the obstacles limiting all but a dozen mathematicians in Britain from understanding *Mécanique Céleste*. Somerville did consistently conclude her investigations by explaining what knowledge had been gained about the celestial bodies, relating this to the importance and fecundity of analytical mathematics, but the general reader had to wade through pages and pages of dense calculations to sift out these points of interest.

Therefore it is perhaps unsurprising that *Mechanism* enjoyed very modest commercial success. Only 750 copies were printed in the end — a print run of 1,000 had originally been discussed — and over a year after going on sale 30 copies remained unsold. The book made a profit eventually, but still John Murray astutely observed that had the larger print run been done this would not have been the case (Patterson, 1983, p. 118).

Nevertheless, *Mechanism of the Heavens* circulated throughout Europe and North America and firmly cemented Somerville's reputation as the queen of nineteenth-century mathematics. Official recognition of her place in the scientific community eventually began to appear — albeit still limited — with the Royal Society commissioning a bust to sit in their meeting room, and discussions on whether a woman could be admitted as a member of a learned society taking place in at least London, Cambridge, and Geneva. Moreover, even with its limitations, *Mechanism* certainly contributed to increasing the visibility of analytic mathematics in Britain, and alongside Bowditch's translation provided a goal for students and interested parties to strive towards. For, as John Herschel noted, if anything would suffice to put English geometers "effectually on their mettle", it would

be being outdone by both an American and a lady (Herschel, 1832, p. 547).

THE UNPUBLISHED WORKS OF MARY SOMERVILLE

Somerville's promotion of analytical mathematics, both to mathematicians and to those natural philosophers who were not mathematically literate, naturally raises the question: How did Somerville, through her own work, continue to advocate for and develop analytical mathematics after *Mechanism of the Heavens*?

A quick glance over a list of her publications offers little insight to the answer. Somerville's subsequent publications were expansive surveys of recent work in the physical sciences, physical geography, and molecular and microscopic science. Somerville's experiments undertaken to investigate the properties of light were brought to the attention of the scientific community through the publication of letter extracts in the journals of the Royal Society of London and the Académie des Sciences, a very common method of circulating one's results at the time (see table 1 for a full list of publications with dates). But none of these endeavours speak explicitly or directly to mathematicians, or prioritise mathematical questions. This is somewhat surprising considering that Somerville explicitly depicted analytical mathematics as a fertile ground waiting to be farmed.

In her *Personal Recollections* Somerville mentioned that during the 1830s she had completed two further books, neither of which had been published in her lifetime. These were a volume on "the form and rotation of planets", intended as a second volume of her translation of Laplace, and an analytical work on curves and surfaces. These works have so far received very little scholarly attention: they are unmentioned in (Neeley, 2001), (Chapman, 2015), nor (Arianrhod, 2012). In Patterson's biography they are but cursorily mentioned, with no additional information except what is given by Somerville in her autobiography. Secord noted their existence in his introduction to *Mechanism* in the collected works of Somerville and conjectured why they remained unpublished, but did not treat them in depth.

That so little attention has been paid to these two book-length works is particularly surprising given that manuscript copies of both are extant to this day.[1] Each manuscript, in Somerville's hand, is contained in a separate brown paper envelope, with a covering note

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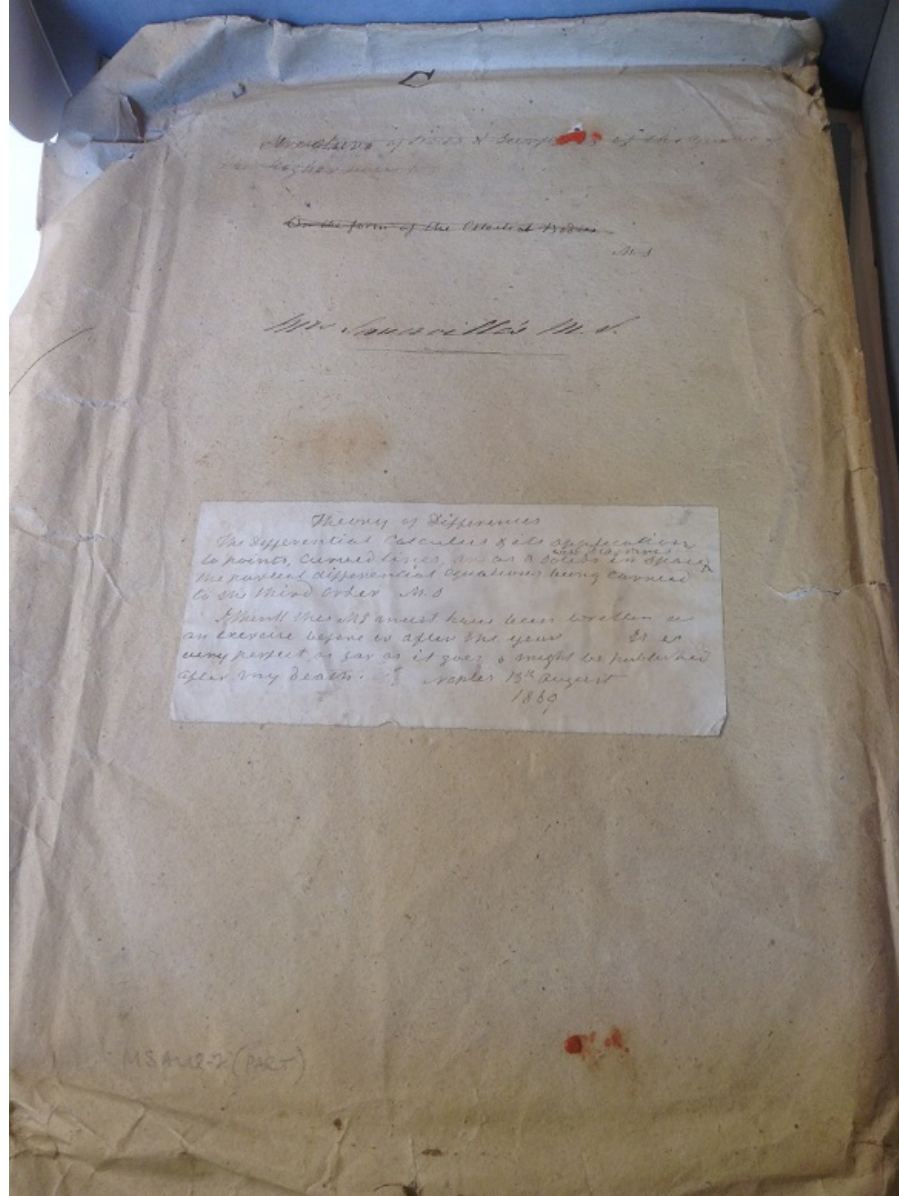1 MS Dep. b. 207, MSAU2–7 & MSAU2–8.

Figure 20: The envelope in which Somerville placed the manuscript of her *Theory of Differences*.

written by Somerville in August 1869 (see figure 20); this reconciles nicely with her recollection that she "repair[ed] the time-worn parts of these manuscripts, and was surprised to find that in [her] eighty-ninth year [she] still retained facility in the "Calculus"" (Somerville and Somerville, 1873, p. 202). It seems that her cataloguing of these manuscripts was part of a wider project to catalogue her letters and papers either during or before the writing of PR. Multiple similar brown envelopes in which she had placed her letters still remain in the Somerville Collection; the letters are ordered alphabetically by correspondent and are often accompanied by notes giving further details on her relationship with, or approbation of, those whose letters she kept. The two manuscripts of mathematical books written during the 1830s were not part of the original collection of papers deposited at Somerville College (and immediately transferred to the Bodleian Library) in 1965, but were part of an addition to the collection deposited in 1972.[2] Little else is known of the lives of the manuscripts, but annotations suggest that Somerville worked on them at multiple times throughout her life.

5.1   ON THE FIGURE OF THE CELESTIAL BODIES

We shall first turn our attention to the manuscript titled by Somerville as *On the Figure of the Celestial Bodies*, henceforth FOB. In PR she described this as a work on "the analytical attraction of spheroids, the form and rotation of the earth, the tides of the ocean and atmosphere, and small undulations". As with *Theory of Differences*, Somerville added a note on the front of the brown envelope in which she stored the manuscript, which read as follows:

> On the Figure of the Celestial Bodies
>
> Probably written after the publication of the Mechanism of the Heavens. The M. S. was in a tattered condition but I have in part repaired it. M. S.
>
> Naples
> 12th August
> 1869

The manuscript does not include a contents page, but it is segmented by frequent headings — there are no distinguishing features between those headings which mark the beginning of an entirely new

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2 Information on the deposition of the manuscripts in the Somerville Collection, Bodleian Library, taken from the Bodleian Library website accessed on 21/01/2020: https://archives.bodleian.ox.ac.uk/repositories/2/resources/3276.

topic and those which separate different areas of the same investigation — these headings have been collected in table 3. Somerville's treatment on the attraction of ellipsoids is at the very commencement of the work, and so it comes under the title of the work rather than a descriptive heading of its own. As can be seen in the table therefore, the extant sheets do treat the topics described by Somerville in PR, and moreover, excepting a detailed study of the comets, this work covers the subject matter of *Mécanique Céleste* which was omitted in *Mechanism of the Heavens* (see Chapter 3). Therefore it seems likely that this manuscript is what remains of her attempts to write a second volume of her translation of *Mécanique Célesete*.

That Somerville did begin writing a second volume is cursorily mentioned in her correspondence alongside PR. In 1832, owing to Somerville's ill health and the outbreak of cholera in London, William Somerville recommended that the family take a trip to Paris. After arriving in September, they were invited to a dinner in Somerville's honour by Alexis Bouvard (1767–1843), an Astronomer who had worked with Laplace at the Observatoire de Paris, where they were joined by the Marquise de Laplace (widow of the author of *Mécanique Céleste*), Arago, and Poisson.[3] Somerville wrote home about the dinner to Woronzow, sharing her delight in the flattery that was given her by "the greatest mathematicians in Europe", especially Poisson's encouragement to write a second volume of *Mechanism of the Heavens* (Patterson, 1983, p. 96). That Poisson's flattery was sincere is suggested by the fact that he later referenced a result from *Mechanism* in one of his papers for *Connaissances des Temps* (Poisson, 1833, Additions, 34). It seems she began working on such a text very soon after; possibly filling her time after finishing a draft of what would become her second book, *On the Connexion of the Physical Sciences* which was given to John Murray's consideration by William on his return to London in November 1832 (Patterson, 1983, p. 119). Murray, and later his son John Murray III, were the publishers of all four of Somerville's books and the *Quarterly Review* which had featured her article on comets.

As in the preparation of her other works, Somerville reached out to her scientific and mathematical contacts in order to gain access to the most up-to-date research in celestial mechanics. Bouvard replied to her requests for astronomical data in late November, giving values for the secular variations in the obliquity of the ecliptic, the mean

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3 Somerville had in fact met Bouvard in London in 1826, and it was Laplace who had written his letter of introduction: MS Dep. c. 371, MSL–2 82, 28/04/1826 Pierre-Simon Laplace to Mary Somerville. Somerville had also written to Bouvard in 1830 requesting biographical information on Laplace for *Mechanism* (Patterson, 1983, p. 70).

Table 3: The headings given by Somerville to partition *On the Figure of the Celestial Bodies*, with page numbers.

motion of the moon, and the horizontal parallax of the sun, taken from multiple sources.[4] Before the end of the year, Somerville had written to James Ivory whose response was in fact quite dismissive of her project. It was his opinion that nothing new could be said on the shape of the Earth until additional data from further experiments became available, and that the theory of equilibrium had not advanced any further than what MacLaurin achieved in his *Treatise of Fluxions* nearly 100 years earlier.[5] Nevertheless, Somerville pressed on, and as was seen in section 3.4, a few months later requested data on the compression of the earth from Francis Baily via her husband.

From the standard of the extant manuscript it is likely that Somerville never produced a completed a full draft of this work, sufficient to convince a publisher to print it for sale. Of the sheets which were written in the early 1830s, many still contain blank spaces where Somerville apparently intended to insert data, formulae, or references to results given elsewhere in the text (FOB, 265, 278). Numerous sheets contain crossings out, with replacements and additions squeezed into margins or between the lines of text, or indeed written on a separate sheet and pasted into the manuscript (FOB, 348, 401). It is possible that she did produce a more complete draft that was lost, but either way there appears to be no correspondence between any member of the Somerville household and the publisher John Murray regarding publishing a second volume of *Mechanism of the Heavens* or a work titled *On the Figure of the Celestial Bodies*.[6] As previously mentioned, the Murray publishing house was loyal and supportive to the Somervilles, and their relationship was both professional and one of friendship (Somerville and Somerville, 1873, p. 220). Thus it seems very doubtful that they would have approached a different publishing house without first approaching the Murrays.

5.2   ON THE THEORY OF DIFFERENCES

We now turn to the second manuscript, *On the Theory of Differences*, henceforth TD, a work on differential calculus with its applications to curves and surfaces. According to Somerville she began writing this after FOB as she "had nothing to do, and preferred analysis to all other subjects" (Somerville and Somerville, 1873, p. 202). The

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4 MS, Dep. c. 369, MSB–10 351, Alexis Bouvard to Mary Somerville, 26/11/1832.

5 MS, Dep. c. 371, MSI–1 6, James Ivory to Mary Somerville, 09/01/1833.

6 Owing to the Covid-19 archive closures I have not been able to check the archives as thoroughly as I would have liked, but no such correspondence was mentioned in (Patterson, 1983) or (Secord, 2004).
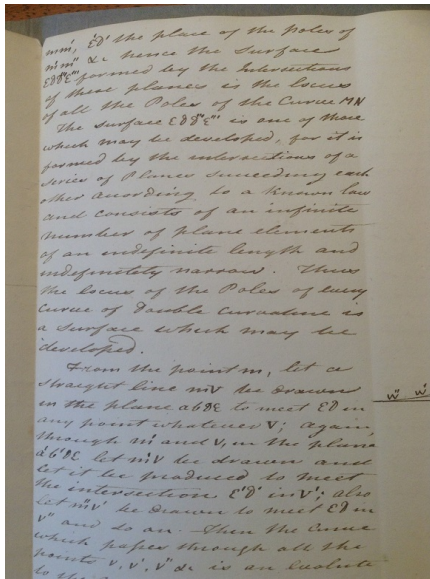
(a) Page 239
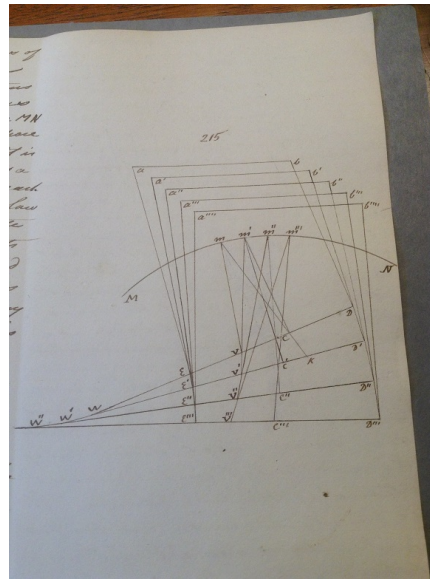
(b) Diagram 215, page 239

Figure 21: Manuscript page 239, with text in the left hand column and a diagram in the right hand column.

manuscript consists of 143 double sided handwritten foolscap sheets, with half of each side devoted to the text and the other half reserved for hand-drawn diagrams, of which there are 216 (see figure 21).

Somerville began the manuscript with a preliminary note which situated the study of the differential calculus within the study of the 'theory of differences', that is the study of variable quantities as they pass through "various states of magnitude". She explained that if a quantity x varies to become $x + h$, the mathematical laws which determine how functions of x vary with h are themselves determined by the properties of h. Somerville identified four different areas of mathematical investigation, depending on whether h is finite or indefinitely small, and determinate or indeterminate: the theory of finite differences (for h finite and determinate); variation of finite differences (for h finite and indeterminate); the differential calculus (for h indefinitely small and determinate); and the method of variations (for h indefinitely small and indeterminate). Somerville concluded the note by writing "the differential calculus is the subject of what follows [and its application to curved lines and surfaces with diagrams]" (TD, 1).[7]

This note formed the entirety of the front matter, after which the main body of the work commenced. It appears that Somerville in-

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7 Any text written as a pencil annotation in Somerville's hand will be quoted in brackets.
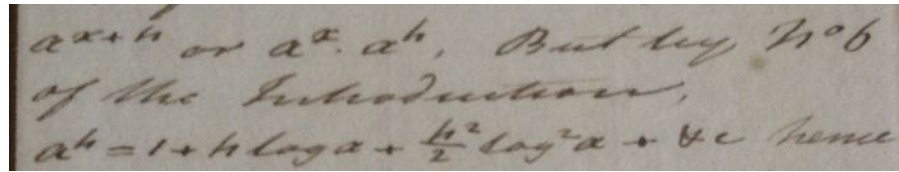
Figure 22: The extract here reads: "But by N⁰ 6 of the Introduction,
$a^h = 1 + h \log \alpha + \frac{h^2}{2} \log^2 \alpha + \&c$" (TD, 19).
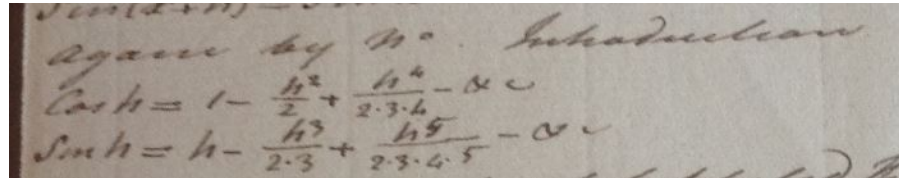
Figure 23: Somerville gives the series expansions of $\cos h$ and $\sin h$ as
"N⁰ Introduction", with no number listed (TD, 24).

tended to include introductory pages containing a numbered list of standard results to aid the reader. This list was referred to numerous times throughout the manuscript, for example on page 19 as shown in figure 22. The standard results quoted include series expansions of logarithms and trigonometric functions, compound angle formula for the sine function, as well as formulae for the angle between two planes in space and the distance between two points in space (TD, 19, 20, 24, 167, 168, 176 and 244). It is unclear whether Somerville ever actually collated this collection of results to be included, or whether she intended to prepare these pages retrospectively once she had finalised the content of the work. The manuscript pages are numbered in pencil in the top right hand corner of each page, beginning at page one and without a gap for missing sheets at the beginning, but this pagination could have been added later or indeed by someone cataloguing the manuscript. On several occasions Somerville referred to a result by leaving a gap to be retro-filled with the correct number of the result in the introduction, such as on page 24, as shown in figure 23. Together with the pagination, this suggests that the list of results was never actually completed, and that Somerville left these in-text references blank, expecting to fill them in at a later stage of production which was never reached.

Table 4: The headings given by Somerville to partition *Theory of Differences*, with page numbers.

Heading	Page
Differential calculus	2
Differentials of the higher orders	12
To find the differential of the transcendental quantity α^x, α being constant	19
To find the differentials of $\sin x$ and $\cos x$	24
On differential equations	27
On changing the independent variable quantity	33
Maxima and minima of functions containing one variable quantity	39
Examples of the developement of functions by the differential calculus	43
Resume Taylors series	46
Applications of the differential calculus to the theory of curved lines	51
On the contact of curves, & the circle of curvature	71
Of certain expressions which cannot be developed by the series of Taylor	93
On implicit functions	103
On quantities which become apparently indeterminate when x has some particular value	108
Examples of multiple and conjugate points	119
When the equation of the curve is an explicit function of x and y	125
On the concavity and convexity of curve lines	131
Recapitulation of some of the circumstances of curved lines, depending on particular values of x	153
Functions of two independent variable quantities	155
Equations in partial differentials	161
Applications of the differential calculus to curved surfaces and lines in space	163
Of surfaces whose equations are in partial differentials of the first order	175
Cylindrical surfaces	180

Again, the manuscript had no contents page but was demarcated by frequent headings which have been collected in table 4. The first fifty pages are devoted to a treatment of differential calculus removed from any applications, beginning with definitions of the differential and differential coefficient of an arbitrary function of a variable quantity, $F(x)$. The definition itself does not offer much practical insight into calculating a differential for a given function, but is followed by a series of constructive rules for calculating differentials which cover some of the standard results still taught today in a calculus class: $d.x^m = mx^{m-1}$ (rule 2, TD, 4); product rule (rule 6, TD, 8); quotient rule (rule 7, TD, 9); chain rule (rule 8, TD, 11); for a constant, $d.a^x = a^x \log a.dx$ (rule 10, TD, 19); and rules for calculating the differentials of logarithmic and trigonometrical functions (rule 11, TD, 20), (rule 13, TD, 24).

Each rule was motivated by a worked example, and followed by numerous more examples which demonstrated to the reader how to calculate the differential of specific functions. This makes clear that Somerville was writing with pedagogical aims in mind, providing the reader with mathematical understanding but also the practical knowledge to calculate the differential of any function whatsoever. The algebraic statement of each rule was confined to the example preceding the rule, with the rule itself written out in prose. For instance, the following extract from (TD, 8–9):

<div align="center">Ex. 23</div>

Let $\frac{x}{y}$ be given, y being a function of x.

Make $\frac{x}{y} = u$ then $x = yu$ and by Rule 6 $dx = ydu + udy$ whence $du = \frac{dx - udy}{y}$ or substituting $\frac{x}{y}$ for u, $du = \frac{ydx - xdy}{y^2}$ the differential of the proposed function.

Rule 7

The differential of a fraction is equal to the differential of the numerator multiplied by the denominator, minus the numerator into the differential of the denominator, the whole being divided by the square of the denominator.

Ex. 24

Let $\frac{x^2}{1-x}$ be given...

As can be seen in table 4, after looking at trigonometric functions Somerville then considered what she called "differential equations". This section in fact looked at implicit functions of two variables, that is functions of the form $F(x, y) = 0$. Here Somerville introduced the notion of 'partial differentials', that is when $z = 0$ is an equation in x and y, then $\frac{dz}{dx}$ and $\frac{dz}{dy}$ are the differentials taken according to x alone, and y alone, respectively (TD, 28). No new notation was introduced to distinguish between differentials and partial differentials. As before, Somerville's investigation culminated in an example, here of finding the differential of $z = 0$, which in turn motivated her rule 14 for finding the differential coefficient, $\frac{dy}{dx}$, from an equation in x and y (TD, 28). The given equation was named the primitive equation, and the equation formed by applying rule 14 was named the first differential equation; rule 14 can then be reapplied *ad infinitum* to give the second, third, ... differential equations.

Somerville subsequently turned to investigations of the properties of functions, through applying the differential calculus. Using Taylor's theorem (which had been introduced earlier in her section on differentials of higher order) Somerville demonstrated that local maxima and minima of functions could be found by solving the equation $f'x = 0$, with the sign of $f''x$ indicating whether $f(x)$ is a maximum or a minimum. After a brief discussion with examples of different ways to represent functions as infinite series (or developements, in the language of Somerville) using differentials, came a discussion on when a function of x cannot be expressed as a series in ascending integer powers of x.[8] Notably, Somerville assumed that all functions can be expressed in such a way *in general*, and that the theory would only fail at particular values of x.

Having given these 50 pages of introduction to the differential calculus, which makes up one fifth of the manuscript, Somerville moved on to applications of the differential calculus to the theory

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8 Somerville attributed the discovery of this series expansion of a function to Maclaurin (TD, 46).

of curved lines. This application of differential calculus was possible as Somerville considered curves which were "expressed by equations" and whose properties were "to be determined from analytical expressions of which the curves are representations" (TD, 51). That is, by considering curves as geometric expressions of equations, or functions, their properties could be investigated in the same way in which the maxima and minima of the functions themselves had been investigated. The rest of the work follows a similar pattern; Somerville alternated between introducing theory and methods of the differential calculus, before returning to the study of curves and surfaces, each time treating ideas more general or advanced.

That Somerville was here using the study of curves and surfaces only as a way of teaching calculus and its applications is evident from her lack of treatment of geometrical ideas. In an early example given to show that additive constant quantities disappear from equations when differentials are taken, Somerville assumed her reader would know the equation for a circle. That is, on showing that the differential of $y^2 + x^2 = a^2$ is $y\,dy + x\,dx = 0$, she explained that the latter equation 'belonged' to the former no matter the value given to a, and later added a note of clarification in the margin which read: "that is $x\,dx + y\,dy$ expresses a property common to all the circles which have their center [sic] at the origin of the coordinates whatever the radius be" (TD, 31).[9] This addition makes clear that Somerville would have expected her reader to be familiar with the general equation of a circle, and how this equation relates to the properties of the circle. Furthermore she used extensive terminology from geometry throughout — such as involute, evolute, and rebroussement — without any definitions given.

As was seen in Chapter 2, the 1810s saw numerous mathematicians adopting and promoting differential calculus — over fluxional calculus — as a way to reform British mathematics and overcome the perceived decline which had begun in the late eighteenth century. A consideration of treatises on the calculus published in Britain around the time that Somerville first wrote this manuscript shows that nearly thirty years later a consensus had still not been reached on which epistemic criteria such texts should be judged, nevermind which principles best satisfied these ideals.

Between 1820 and 1840 at least 36 treatises on the differential and integral calculus were published in Great Britain and Ireland, by 25 distinct authors (not counting multiple editions of the same work

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9 Somerville used 'American' spelling frequently in her letters and manuscripts, for words such as center, color etc.

separately - see table 5 in appendix E).[10] Of those for which digitised copies were available, fourteen specifically mentioned, either in their title or preface, as being designed for university students, with many of the works printed by printers affiliated to a university. All of the works listed a publisher or bookseller in at least one of the English university towns of Oxford, Cambridge, or London. Twenty-seven listed at least one publisher or bookseller located in Cambridge, often alongside a second bookseller in London, and a further two were published in Oxford — both written by Baden Powell, holder of the Savilian Chair of Geometry at Oxford University. Moreover, of the 25 authors of these works, 18 were fellows of a Cambridge college, and the remaining seven consisted of two professors of Natural Philosophy and Astronomy at the University of London, John Forbes who identified himself as the minister of St Paul's in Glasgow, and professors of mathematics at: Belfast College; the University of Glasgow; the University of London; and the University of Oxford (see table 6 in appendix E).[11]

There are two common factors which stand out as motivations for the authors of these works. The first, was a need to underscore and defend the place of mathematics within a gentleman's education. Both Powell at Oxford, and Whewell at Cambridge, were motivated to write their texts by the desire to show the utility of higher mathematics as part of a gentleman's liberal education (Whewell, 1838, p. vii), (Powell, 1830, p. iiv).[12]

The second, was the desire to demonstrate the *principles* of the differential calculus in a clear, consistent and well-reasoned fashion.[13]

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10 This list of titles was mined from the online catalogues of the Bodleian Library, Oxford, the University Library, Cambridge, and the British Library, London on 29/02/2021.

11 One of the professors at the University of London, William Ritchie, was likely the same Dr. Ritchie who had taken out Somerville's *Mechanism* from the library of the Royal Society (section 4.5) and who sourced the geometrical models for Ada Lovelace on the solicitation of Somerville (section 3.2).

12 For more on Whewell and mathematics at Cambridge, see (Becher, 1980).

13 These two factors were certainly not commensurate and produced further tension and disagreement around the best way to teach mathematics, and the calculus specifically, to a university student. Indeed, one author, Arthur Browne, reminded his readership that universities were not formed to "enlarge the bounds of scientific knowledge … [but to] continually yield a supply of men, well qualified to fill the various offices, both in Church and State" (Browne, 1824, p. xv). Browne was evidently not concerned with any decline in British mathematical research, nor did he feel it the role of a university to fix one should it arise. It was far more important to him that each man should leave Cambridge having learnt how to think, than that a few men should leave with the skills to pursue original research. It was geometry which Browne saw as a way to inculcate his students with the correct habits of thought, and that any student "who by studying the *French analytical writers*, has at

Arthur Browne, a fellow of St John's College, Cambridge accused mathematicians of a shallow understanding of the calculus; he felt that they could "dispatch fluents and fluxional equations with inconceivable rapidity" whilst having "very vague and confused ideas of the principles by which they work" (Browne, 1824, p. xxii). Meanwhile Powell found that all existing treatises gave a deficient treatment of the fundamental principles (Powell, 1829, p. iv). As late as 1837, Forbes made reference to ongoing "metaphysical and mathematical difficulties" which hindered the diffusion of differential and integral calculus (Forbes, 1837, p. vi).

Each author had their own idiosyncratic ideas of how a rigorous treatment of the principles of differential calculus could or should be achieved. Broadly speaking, the authors tend to fall into two different categories: those who adopted the work of Lagrange and aimed for what was termed a 'purely algebraic' form of differential calculus, and those who adopted limits or ratios.[14]

For a function of x, say $f(x)$, the method of limits or ultimate ratios found the differential of a function by considering the ratio of the increment of the function with the increment of the variable on which it depends. That is to say, the change in $f(x)$ which occurs when x becomes $x + h$, which can be represented as

$$\frac{f(x + h) - f(x)}{h}.$$

The differential captured the instantaneous change in $f(x)$, taking the value which this quantity approached as h became "less than any [quantity] that can be assigned in finite terms" (Hind, 1831, p. 1). These were not the rigorous limits standard in calculus today which were first introduced by Cauchy in Paris in the early 1820s. None of the works considered here made reference to Cauchy and instead made recourse to either Newton or D'Alembert to situate their work within a mathematical canon.

The Lagrangian calculus was a calculus of *functions*. That is to say, for a function $f(x)$, where x is a variable quantity and h the change in x, the expansion

$$f(x + h) = f(x) + Ah + Bh^2 + \dots \tag{7}$$

is assumed to exist in general, with $A(x)$, $B(x)$ ... also functions of x. The derived function (fonction derivée in the original French, and

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length acquired their obscure and confused manner of thinking ... will, (if he ever enters the world) enter it with a mind that must be re-modelled" (emphasis my own) (Browne, 1824, p. xi).

14 Owing to the Covid-19 closure of archives, this discussion is limited to those texts for which digital versions could be accessed.

sometimes called the differential coefficient) is then *defined* as the co-efficient of h in the expansion. Lagrange used the notation of $f'(x)$ to denote the first derived function, in order to show the inherent relationship between itself and f. As $f'(x)$ was itself a function of x this process could be repeated to arrive at the second, third, and so on derived functions denoted as $f''(x)$, $f'''(x)$ respectively. This new mathematical object, the derived function, then took the place of the differential in the methods of the calculus. Lagrange introduced these ideas in his major work *Théorie des fonctions analytiques* published in 1797, the full title of which translates to *Theory of analytical functions containing the principles of the differential calculus disengaged from all consideration of infinitesimals, vanishing limits or fluxions and reduced to the algebraic analysis of finite quantities* (Lagrange, 1797), (Fraser, 2005, p. 261).[15]

A majority of the calculus texts surveyed chose to base their explanation of the differential, and the differential calculus, on limits. Some authors offered a justification for this choice, critiquing Lagrange's work for its reliance on a series expansion of a function which is not always defined for every value of x. However, a significant number of texts chose to present both formulations to their reader. Thomas Jephson, another fellow at St John's College, Cambridge, claimed that "the two systems meet in Taylor's Theorem, and that being once established the difference [between them] is merely nominal" (Jephson, 1826, p. iiv); similarly (Ottley, 1838, p. vi) attempted to show that the definition from 'Lagrange's system' coincided with that of the system of ultimate ratios, meaning that the reader was at liberty to use either of them.

We consider here Somerville's definition of a differential in TD as one written by someone seen by her contemporaries as an expert in 'French analytical mathematics', especially in the differential calculus which was necessary to understand Laplace's *Mécanique Céleste*. Her definition shows clear influence from the work of Lagrange and Lacroix, perhaps mediated through the 1816 translation of Lacroix produced by the Analytical Society (Lacroix, 1816).[16] Not unusually for the time, Somerville did not give a definition of a function, or attempt to outline or limit what she meant by a function of a variable quantity.

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15 For a treatment of the principles of the calculus at the turn of the nineteenth century see (Caramalho Domingues, 2008), especially Chapter 3.

16 For the full transcribed extract where Somerville defines the differential, see appendix F. The annotation here has been slightly amended for clarity: $F(x)$ is used in place of Fx to indicate the value of a function F evaluated at a point x.

Her definition of a differential began with the derivation of a series expression for $F(x + h)$ in whole and positive powers of h, where F is an arbitrary function of x, and h is the increment. This was achieved by considering the difference

$$F(x + h) - Fx = \Delta \tag{8}$$

where Δ is a function of x and h that vanishes (becomes equal to 0) when $h = 0$. Somerville claimed that it was always possible to find a new function φ such that

$$\Delta : h :: \varphi(x + h) : 1.$$

Substituting φ into equation 8 then gave

$$F(x + h) - Fx = h\varphi(x + h).$$

As $\varphi(x)$ is a function "in all respects similar to $F(x)$" this process can be iterated indefinitely to obtain the following series expansion of $F(x)$:

$$F(x + h) - Fx = \varphi(x) \cdot h + \varphi'(x) \cdot h^2 + \varphi''(x) \cdot h^3 + \&c$$

where the functions $\varphi, \varphi', \ldots$ are indeterminate functions of x.

Somerville claimed that h could be made sufficiently small that the first term of the series could be taken in place of the whole difference, and in this case the above expression became

$$d \cdot F(x) = \varphi(x) \cdot dx.$$

Somerville named $\varphi(x) \cdot dx$ as the differential of $F(x)$, and $\varphi(x)$ as the differential coefficient. This definition was immediately followed by the constructive rules for calculating the differentials of functions, outlined above. Somerville's presentation of the differential calculus suggests a strong influence from (Lacroix, 1797–1800), which she certainly read before writing TD as she referenced a standard integration result from it in *Mechanism* (section 4.4). Similarities include alternating between using differentials and differential coefficients in calculations — which were commonly denoted by dx and $\frac{dy}{dx}$ respectively in both works — and even the term differential coefficient was first introduced in Lacroix (Caramalho Domingues, 2008, p. 73). Somerville had in fact met Sylvestre-François Lacroix (1765–1843) in Paris in the early 1830s, and she described him as the person "to whose works [she] was indebted for [her] knowledge of the highest branches of mathematics" (Somerville and Somerville, 1873, p. 185).

Unlike many of the other authors of calculus texts here discussed, Somerville did not offer her reader any critical reflection on her choice of definition for the differential. In fact, after noting that dx was "indefinitely small" she went on to say that $\varphi(x)$ can be calculated by dividing the differential of the function by dx, even though this division by an infinitesimal had been one of the main areas of critique of the differential calculus for over 100 years.

Nevertheless, she did seem to be aware of the limitations of her reliance on series expansions of functions as part of her derivation. She explained to the reader that the form of the series expansion, in whole and positive powers of h, was an *assumption* as the expansion does not always necessarily take this form. She then informed the reader that if the assumption was erroneous, they would know from a contradiction (or 'absurdity') arising when calculating the coefficients $\varphi(x)$, $\varphi'(x) \ldots$

However, just because she offered little explanation to the reader does not mean that Somerville was merely uncritically reproducing ideas in the writing of TD. Over ten years earlier, Somerville had made at least two attempts to prove that a function could always be developed into a series which ascended in "whole and positive powers of the increment". These attempts are located in an entry of the same notebook in which Somerville had copied up her solutions to puzzles published in the *Mathematical Repository* (see section 2.4); the entry has been reproduced in Appendix G. As in TD she began by considering the function $\Delta = F(x + h) - F(x)$, but then made a more general assumption that a function $\varphi(x + h)$ can always be found such that $\Delta : h^n :: \varphi(x + h) : 1$, and attempted to *show* that n must be equal to 1. Somerville did this by finding a new expression for $F(x + h) - F(x)$ in terms of x, h and i, where $i = x + h$, and with an application of the binomial theorem deduced that n must satisfy

$$1 = n - \frac{n(n-1)}{2} + \frac{n(n-1)(n-2)}{2 \cdot 3} - \&c. \tag{9}$$

She noted that $n = 1$ evidently satisfies this equation (as all terms after the first on the right-hand-side reduce to 0), and the argument continued as it was given in TD. However, after the conclusion, Somerville added the following passage:

> At first I thought I had proved this Theorem but upon further consideration it appears, that in the equation $1 = n - \frac{n(n-1)}{2} + \frac{n(n-1)(n-2)}{2 \cdot 3} - \&c$ a value has been <u>assumed</u> for n among an indefinite number that might equally have satisfied it, consequently it is not a demonstration, and indeed no demonstration has yet been give of this Theorem,

for La Grange and all the other mathematicians who have written on the subject have virtually assumed that the series would ascend by the whole and positive powers of the Increment in place of proving it. It may be even doubted whether it ever can be demonstrated and perhaps the best way is to make the assumption of the easiest law such as the whole and positive powers of the Increment and it if be wrong the error will become manifest by some absurdity arising in he determination of the coefficients.

It is curious that she should specifically name Lagrange as a mathematician who "virtually assumed" this key step in the derivation of a differential (or derived function in his case). As was noted in Chapter 2, one of the earliest advanced mathematical texts that Somerville was able to add to her personal library was a copy of Lagrange's *Théorie des fonctions analytiques*, which appears to have been gifted to her by William Wallace in the mid 1810s. On page 7 of this book, Lagrange explicitly referred to the importance of proving *a priori* that such a series expansion exists and that it would not contain any fractional powers of h, unless x was given a particular value (Lagrange, 1797, p. 7).[17] However, as early as 1803, Woodhouse in Cambridge rejected Lagrange's proof as he objected to its implicit reliance on a limit process (Guicciardini, 1989, p. 128). Somerville was certainly aware of the work of Woodhouse, as she referenced his work in *Mechanism* and owned his book on *Isoperimetrical Problems*. Therefore, by searching for her own proof that such a series expansion exists for every function, Somerville was implicitly rejecting the demonstrations given by Lagrange and Woodhouse and showing herself to have been a critical and thoughtful reader.

Although she was clearly part of the community of mathematicians who saw French analytical mathematics as being a more fruitful area of research than the mathematics practiced in Britain, this did not mean that in her work she mindlessly regurgitated the ideas of the foreign authors she had studied. Her ongoing discomfort with making such a large assumption in a definition fundamental to the study of differential calculus is manifest in the notebook entry which contains a second attempt at a proof using repeated application of differentiation, but Somerville concluded it with "n is here assumed as

17 See (Caramalho Domingues, 2008, p. 81) for cases where the Taylor series does not apply in the work of Lagrange and Lacroix. Note that Lagrange uses i to represent the increment, rather than h; I retained Somerville's notation here for clarity.

much as in the 1st case" (see appendix G).[18] Perhaps she felt that such uncertainty was not well-placed in a textbook aimed at students being introduced to the methods of differential calculus for the first time, and therefore chose to alert the reader to the possibility of the expansion not existing in the given form, without entering into the details.

After the publication of *Mechanism of the Heavens* and its overwhelmingly positive reception, Somerville's reputation as an expert in analytical mathematics and physical astronomy was indisputable. However, as can be seen in table 6, all but six authors of the other calculus textbooks written between 1820 and 1840 had sat the Mathematical Tripos at Cambridge, and attained the prestigious title of Wrangler in their final exams. Both Lardner and Powell had studied at universities other than Cambridge (Dublin and Oxford respectively), and applied for their reciprocal MA from Cambridge. Although it was possible to study mathematics at other universities in Britain, Cambridge was by far the most prestigious place to do so, and it was not unusual at the time for students to study at one of the Scottish or London universities before then sitting the Tripos exam.[19] Therefore, Somerville was at a serious disadvantage in attempting to write a textbook for British students, having never attended such an institution herself.

As was made clear in Chapter 2, one of the greatest advantages in Somerville's independent education was that she was not exposed to or inculcated with the 'prejudices' of a Cambridge education. This was essential to the trajectory of her mathematical studies which enabled her to produce a widely acclaimed translation of *Mécanique Céleste*, but became a disadvantage when attempting to write a text for students who were often more interested in passing exams than becoming researchers. Although her son attended Trinity College, Cambridge, the deepest she herself was able to penetrate into the hallowed halls of Cambridge University was a week-long visit in 1832 (see section 3.2). As much as this will have indubitably strengthened Somerville's social connections to the Cambridge scientific and

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18 I have here resisted the temptation to attempt to highlight where and how Lagrange and Somerville's proofs "went wrong"; they were both operating without concepts such as the radius of convergence of a power series, or a distinction between different types of function such as continuous, differentiable, continuously differentiable etc. Somerville's second attempt at a proof relied on concepts of differentiation, so would have introduced circular logic had she relied on it to ensure her definition of a differential was well-defined.

19 Although it was home to the largest group of students studying mathematics in Britain, it is worth noting here how small the community of Cambridge educated mathematicians actually was; in the 1820s Cambridge admissions were at around 400 students a year (Warwick, 2001, p. 24).

mathematical communities, no mention is made of her attending lectures or gaining insight into the student experience of studying for the Tripos. Moreover, Somerville appears to have become acquainted with the professors rather than the men who worked as private tutors, and it was the latter who exerted the biggest influence over the studies of the undergraduates with hopes of achieving top results in their final examinations during the 1830s (Warwick, 2001). An example of such prejudice against those who did not themselves study at the University of Cambridge is offered by Henry Brougham, who in 1839 published a dissertation on Newton's *Principia* (Brougham, 1839, p. 243). According to a letter by him written to Somerville in 1840, "Cambridge men" admitted that his essay was was "well calculated for teaching [the *Principia*], yet, *not being by a Cambridge man*, it cannot be used!" (Somerville and Somerville, 1873, p. 237).[20] Therefore Somerville would have found it far more difficult to know where a study of differential calculus fit into the usual progression of studies at the university, and did not possess the suitable social connections or education to ensure that her work would actually be used by tutors and their students.

The volume of introductory treatises on the calculus in the 1830s clearly indicates that there was an appetite for a book that would treat the differential calculus in an accessible way, while avoiding the metaphysical pitfalls of limits and series expansions. However, Somerville's work neither offered a definitive solution to this tenacious issue, nor was it written by an author who wielded intellectual authority in the male-dominated space of British universities.

5.3   CHOOSING TO PUBLISH A 'POPULAR' WORK

It is probable that work on FOB and TD was in fact derailed by work on *Connexion*, which in April 1833 Murray accepted for publication. Throughout May and June Somerville was busy revising the proof sheets that were shuttled between Paris and London in the Embassy postbag, thanks to the generosity of Lord Granville, then British ambassador to France (Patterson, 1983, p. 119). Revisions continued after Somerville returned to London in late summer 1833; the book was so hotly anticipated that the manuscript sheets were requested by James David Forbes and Charles Lyell, both of whom responded in kind with suggested changes and improvements. The manuscript was also seen by Henry Holland, William Whewell, Henry Brougham and Michael Faraday, all of whom used their own expertise to inform

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20 Emphasis from the printed source.

Somerville of relevant experiments or recent scholarship which she subsequently included in her own book (Patterson, 1983, pp. 131–135).

As well as a determination to include accurate summaries of the most recent scientific discoveries, it is very clear from her correspondence that Somerville was conscious of a need to make her second book more "popular" somehow. In a letter to William Somerville in March 1833, reporting on the profit generated by sales of *Mechanism*, Murray shrewdly pointed out that had 1000 copies been printed as was initially intended then in fact the work would have made a loss and 280 copies would have been left unsold (Patterson, 1983, p. 119). Two weeks later Somerville wrote directly to Murray herself to express her thanks for him interesting himself in her work and agreeing to publish a book whose potential for commercial success had been far from certain. She additionally expressed her happiness that he had ventured to publish her "new attempt", and her hopes that it would be more popular as she had done all she could to make it so.[21]

In order to broaden the readership of her work, the most substantial change Somerville made to her writing in the preparation of *Connexion* was to remove all algebraic formulae. Significant portions of the text were lifted directly from the Preliminary Dissertation, and much of the other content had previously been treated mathematically in the main body of *Mechanism* (Secord, 2004, ix, Vol 1). But, rather than being peppered in amongst abstract mathematical formulae and intimidating calculations, the information about the movements and structures of the bodies in the solar system was made the *focus* of *Connexion*.

Notably, Somerville retained her allusions to the power of analytical mathematics, and its importance in the studies of the physical sciences. The passage from the Preliminary Dissertation encouraging all readers to study analysis to a level sufficiently high enough to appreciate the study of physical astronomy was repeated at the beginning of *Connexion* (Somerville, 1834, p. 5). That Jupiter's moons are too small to be measured, yet their masses can be accurately measured from the perturbations of their orbits was given as "a striking proof of the power of analysis" (Somerville, 1834, p. 29); the deduction that the earth is not a permanent magnet but in "a state of transient magnetic induction" was the result of "profound analysis" by Poisson (Somerville, 1834, p. 349); and the 'connexion' between the physical sciences was proposed by Somerville to be "analysis, which... will ultimately embrace almost every subject in nature in its formulae"

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21 NLS, MS 41131, folio 75, Mary Somerville to John Murray, 2/04/1833.

(Somerville, 1834, p. 413).[22] Therefore, although the mathematical formulae themselves had been removed, their influence and presence was felt throughout the work, and Somerville continued to advocate for the study of analysis.

As well as removing the formulae, Somerville added a 35-page 'explanation of terms' to aid the reader with the frequently used technical jargon, and the book was advertised by Murray as an enlarged and adapted version of the Preliminary Dissertation which was suitable for a general and unscientific reader.

Whereas *Mechanism* was given an initial print run of 750 and experienced lethargic sales, the first edition of *Connexion* had an initial run of 2000 copies which were nearly all picked up by booksellers within a month of publication in February 1834. Indeed, in June 1834 Murray sent Somerville two-thirds of the profit so far generated, which amounted to £144.18.10 and already exceeded the total profit made from sales of *Mechanism* (Patterson, 1983, p. 136).[23] Only two months later Somerville began the process of preparing a second edition of *Connexion*, which was printed before the end of 1834 and again sold out within months, so that in June of 1835 Somerville received her share of the profits which amounted to £361.6.3 (Patterson, 1983, p. 146). The experiment in writing a more 'popular' work was clearly a resounding success, and it is unsurprising that Murray, had he known of Somerville's intention to write a second volume of her translation of *Mécanique Céleste*, would prioritise a second edition of *Connexion* rather than take a fiscal risk with another highly advanced mathematical book.

Somerville herself had her own reasons to prioritise authorial projects that would generate an income, beyond just solidifying her reputation as an expert or furthering the cause of analytical mathematics in Britain. To move in the social circles which both Somerville and her husband enjoyed frequenting was a costly business; from keeping up with the latest sartorial fashions, to renting a house on the fashionable Curzon Street, William's salary of £1200 a year was often insufficient as their only form of income.[24] In June of 1832 Somerville wrote to her friend Anna Horner, "We remain at home, indeed we shall be sta-

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22 As in *Mechanism*, Somerville then connected the study of analysis to a study of the omniscient Creator: these formulae having been "implanted... in the breast of man when He created him after His own image" (Somerville, 1834, p. 414).

23 The profit from *Mechanism* amounted to £142.17.6 (Patterson, 1983, p. 117).

24 (Boot, 1999) looks at the incomes of the middle classes in Britain in the first half of the nineteenth-century through a study of the salaries of clerks at the East India Company, which ranged between £600 to £1000.

tionary all summer moving is so expensive"(Patterson, 1983, p. 94).[25] Furthermore, she wrote in the manuscript of her *Personal Recollections* how she was unable to attend performances of Italian operas as frequently as she would have wished, as she "could only afford to take a box now and then".[26] Whilst these superficial economies hardly pull at the heartstrings, the ability to maintain her reputation as a respectable lady, and William's reputation as a clubbable gentleman, were vital to her continued access to polite scientific society and these small sacrifices demonstrate that this was not something she could take for granted.

In addition, the Somervilles faced serious financial setbacks in the 1820s and 30s. The first was in 1823, when Samuel Charters Somerville, William's brother, left a large debt on his death which the Somervilles were forced to take responsibility for, to avoid the shame of a posthumous bankruptcy in the family. Disaster struck again in 1830, once more due to the selfish actions of people close to the Somervilles; Henry Lowe, the man entrusted by William Somerville with the family's Scottish business interests, placed the Somervilles in financial uncertainty when he absconded after being accused of breaking the law (Patterson, 1983, pp. 170–171).

In March of 1835, Somerville recieved a letter which must have offered her a welcome respite. Sir Robert Peel, then Prime Minister of England, wrote to her with his plan of advising His Majesty King William IV to name Somerville on the Civil List, and thus grant her a yearly pension of £200 in perpetuity with the intention of reducing any anxiety which arose due to Somerville's scientific studies (Somerville and Somerville, 1873, p. 177). The value of the pension came from a recommendation made by John Wilson Croker, an Irish MP, who had enquired after the financial situation of the Somervilles, and discovered the entire family's reliance on the salary of Dr. Somerville (except for Woronzow, who had inherited his father's wealth). £200 a year was a large pension to be awarded to a scientist, and was far larger than those usually awarded to women (who were more often given pensions for their literary contributions).[27]

But only four months later the Somervilles found themselves in the worst financial situation yet when James Wemyss, a first cousin of both of them, fled abroad when he could not repay the loans he had taken out to cover his gambling debts. Unfortunately, William

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25 Anna Horner was the wife of Leonard Horner who had written the Somervilles a letter of introduction to the Marcets in 1816 (see section 3.1.)

26 MS Dep c. 355, MSAU-2.

27 For more on the politcal implications of Somerville's pension see (Patterson, 1983, pp. 152–158).

had stood surety for Wemyss and so the repayment of these loans fell to him. In addition, Wemyss had left behind three unmarried sisters who had no income of their own and hence no way to provide for themselves (Patterson, 1983, p. 170). This debt affected the Somervilles for many years, as the only way they were able to repay it was through yearly instalments. [28] Somerville described her shock at the betrayal of her cousin as like being hit by a thunderbolt. She was devastated that her financial freedom had been so fleeting. She soon realised how lucky she was that the pension had been awarded in time to avoid "utter ruin", and that she did "thankfully and cheerfully yield it up to such a purpose". [29] From then on Somerville took a much more involved role in the family's finances; she wrote to Woronzow, "I have been too long a passive spectator in events & transactions which concern me more nearly than anyone else, but now that the existence of my children is at stake I shall take the management of affairs into my own hands."[30]

Somerville's burst of productivity in the early 1830s seems to have been strongly influenced by this financial pressure. Indeed, when discussing the first edition of *Connexion* with Woronzow, she specifically mentioned her aspirations for the good *sales* of the work, rather than merely hoping to write a work that was deemed popular (Patterson, 1983, p. 119). By writing three starkly different styles of book, she multiplied her chances of commercial success — a translation of Laplace to appeal to those who wished to reform British science, a textbook to appeal directly to the university student market, and an expansive survey of recent scientific scholarship for those without mathematical training.[31] All three were underpinned by her interest in and advocacy of analytical mathematics, which Somerville identified as the common thread which connected all of the physical sciences.

The overwhelming success of *Connexion* quickly rendered the other two texts obsolete. For the reasons discussed above, *On the Theory of Differences* was unlikely to corner a large market in the university textbook trade, and *On the Figure of the Celestial Bodies* was unlikely to exceed the limited success of *Mechanism of the Heavens*.[32] It is probable that Murray, who beyond publishing Somerville's books was also a

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28 MS, Dep. c. 361, Folder MSIF–1, Mary Somerville to Woronzow Greig, 6/08/1835 and 15/06/1835.

29 MS, Dep. c. 361, Folder MSIF–1, Mary Somerville to Woronzow Greig, 8/07/1835 and 13/07/18835.

30 MS, Dep. c. 361, Folder MSIF–1, Mary Somerville to Woronzow Greig, 8/07/1835.

31 As pointed out by Secord, *Connexion* was hardly suitable for a general audience as it covered complicated scientific theories utilising extensive technical language.

32 For a study of someone who successfully made a career in writing mathematics textbooks in the mid 19th century see, (Barrow-Green, 2001) on Isaac Todhunter.

friend of the family, was aware of their precarious financial position from very early on. He took no cut for himself from the modest profits generated by *Mechanism*, and for all of Somerville's subsequent books he took only one-third of the net profit for himself when his usual arrangement was to divide the profit equally between himself and the author. Thus the choice to leave FOB and TD unfinished and unpublished was perhaps an informed and mutually beneficial decision, rather than a unilateral decision by Murray. Either way, the manuscripts were left aside and Somerville instead worked on her article on comets for the *Quarterly Review* — for which she was paid a fee — and new editions of *Connexion* which were issued in 1836 and 1837.

In 1838 the Somervilles' lives were changed dramatically by the ill-health of William, which prompted the decision to leave London's lively scientific scene behind for a warmer climate. Originally intending to return after only a few months, the Somervilles never again took up residence in London, and Patterson describes the final thirty years of Somerville's life as "outside the mainstream of science" (Patterson, 1983, p. 189).

5.4 A LIFETIME OF WORK

That Somerville herself felt isolated from 'the mainstream of science' is evident throughout her letters and *Personal Recollections* — complaints of books being unavailable, or in languages that she could not read, are easily found.[33] Nevertheless, Somerville actively pursued her scientific interests, as is clearly evidenced by the books that she continued to publish. Five more editions of *On the Connexion of the Physical Sciences* appeared during her lifetime, as well as two completely new surveys of scientific literature, one looking at *Physical Geography* — which went through six editions in her lifetime — and in 1869 a second looking at *Microscopic and Molecular Science*.

Although her resources were not as numerous or convenient as they had been in London, Somerville was able to use the libraries of her contemporaries as she moved about Italy. In Florence she had use of the library of the Grand Duke of Tuscany, Leopold II (1824–1859) where she could read the transactions of the astronomical and

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33 Somerville wrote the following to Henry Holland in 1859: "It is a great disadvantage being so entirely deprived of scientific society and of the means of hearing of recent discoveries and new publications except from such journals as I can procure." Letter held by Somerville College, Henry Holland to Mary Somerville, 05/01/1859. See also Somerville's letters to John Murray, NLS MS 41131, 163 & 179 & 189.

royal societies, whilst in Turin she used the library of the Professor of Astronomy at the university, Giovanni Plana (1781–1864) (Patterson, 1983, pp. 190–193), (Neeley, 2001, p. 81).[34] In an unusually negative sentiment regarding algebra, Somerville complained that her only scientific acquaintance in Turin was Plana "who [was] very clever and very agreeable but he [was] devoted to xes and ys more than to general subjects".[35] Somerville frequently received books from her publisher John Murray III, either directly on her request, or on the advice of her correspondents who she asked to give Murray a list of the most recent texts in a given subject so he knew which books she should be sent.[36] Murray also forwarded books to Somerville on behalf of others. For example in 1869 Charles Lyell sent a new edition of his *Principles of Geology* via Murray who had a "reliable channel" to send books internationally.[37] Michael Faraday (1791–1867), Fullerian Professor of Chemistry at the Royal Institution, was an immensely supportive scientific colleague, sending numerous offprints of his papers to Somerville, as well as assisting with corrections for *Connexion* and *Physical Geography*.[38] Furthermore, Somerville continued to be elected an honorary member of scientific academies in Italy, including the Reale Academia Valdarnesse, Academia Tiberina, Pistoia Academy, Società Geografica Italiana, as well as the American Geographical & Statistical Society and the American Philosophical Society in the United States of America.

What is less evident in previous scholarship is how, or indeed if, Somerville continued her engagement with mathematics and mathematical communities after moving to Italy.

It is immediately possible to say that yes, Somerville did indeed continue her study of mathematics. This pursuit was described by her daughter Martha in PR as the one she found "most congenial", that Somerville "always retained her habit of study", and that even

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34 On Florence: NLS MS 41131 89, Mary Somerville to John Murray III, 03/04/1842 and a letter from Mary Somerville to Henry Holland dated 05/01/1859 held at Somerville College. On Turin: NLS MS 41131 104, Mary Somerville to John Murray III, 21/03/1850.

35 NLS MS 41131 104.

36 NLS MS 41131 137 & 146 & 159

37 MS Dep. c. 371, MSL–6 145, Charles Lyell to Mary Somerville, 05/01/1869. See also MS2 CELE 8, Michael Faraday to Mary Somerville, 17/01/1859, where Faraday informs Somerville that he will ask Murray to send a copy of his new work once it is ready.

38 13 of the offprints are in the Girton College Library: Somerville Collection, the catalogue of which can be consulted online. See also a letter from Somerville to Faraday 12/03/1853, where she thanks him for sending her his papers: "Faraday2653," in εpsilon: The Michael Faraday Collection accessed on 10 May 2021, https://epsilon.ac.uk/view/faraday/letters/Faraday2653.

into her ninety-first year Somerville "rejoiced to find that she had the same readiness and facility in comprehending and developing extremely difficult formulae which she possessed when young" (Somerville and Somerville, 1873, pp. 376–7). Indeed, according to Martha, Somerville was working on the manuscript of *Theory of Differences* the day she died, as well as reading a book on quaternions.

As has been previously mentioned, Somerville's collection of scientific and mathematical books was donated to Girton College, Cambridge after her death. This collection has been catalogued in great detail, and offers helpful insight into the books that Somerville was able to add to her personal library after moving away from London — in addition the telling phrase "many pages left uncut" in the catalogue notes makes clear which of these books Somerville actually chose to read![39] In total, there are 30 items in the collection which could be loosely classified as 'mathematical' and were published after 1838; these are a mixture of published books and offprints of papers, in English, French, and Italian.

As a testament to Somerville's standing within the mathematical community across Western Europe, 21 of these works are inscribed to 'Mary Somerville, with the compliments of the author' (or a variation thereof), with a further three works sent with compliments from a third party. That authors continued to want the approbation of, and social connection to, Somerville is a clear signal of her ongoing respect in the mathematical community. In the century of the grand tour, Somerville was often visited by savants as they travelled through Italy. Benjamin Peirce, Professor of Mathematics and Astronomy at Harvard University in the USA, came to Europe in 1870 to view an eclipse, and whilst in Naples paid Somerville a visit. He was so enamoured, that on his return to the USA he sent her a privately printed copy of his paper titled 'Linear Associative Algebra', inscribed "To the brightest glory of her sex, Mrs Mary Somerville, with the sincere admiration and the profound respect of the Author".[40]

That Somerville was not merely a passive member of the mathematical community, content to receive visitors and to hear their flattery with no interest in engaging with new work, is evidenced by her response on receiving Peirce's 133-page paper. The reception of *Linear Associative Algebra* was quite cold in both the USA and Europe, with even the mathematicians who persevered through the "vague and in

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39 In the 19th century it was still common for books to be sold with the pages left uncut — that is, when the large printed sheets were folded and then bound, the folds between subsequent pages were left to the purchaser to cut so that they could access the inner pages.

40 Girton College Library: Somerville Collection (073121).

some cases unsatisfactory proofs" considering it to be a philosophy paper rather than a mathematics paper (Pycior, 1979, p. 548).[41] It certainly challenged Somerville's comprehension, so much so that she felt obliged to write to William Spottiswoode (1825–1883), then President of the London Mathematical Society for assistance (Somerville and Somerville, 1873, p. 356).[42] Spottiswoode recommended three alegbra textbooks: Serret's *Algèbra superieur* (Serret, 1866); Salmon's *Higher Algebra* (Salmon, 1866); and Tait's *Quaternions* (Tait, 1867).[43] All three of these works are in the Girton Somerville Collection, and were inscribed by Somerville with her name.[44] Even into her 92nd year, losing her hearing and her memory of names and events, Somerville continued to study "higher algebra" for five hours every morning including solving problems. She admitted:

> Sometimes I find them difficult, but my old obstinacy remains, for if I do not succeed to-day, I attack them again on the morrow (Somerville and Somerville, 1873, p. 364).

This interlude demonstrates that rather than being put off by having fallen behind research in algebra, Somerville instead was grateful to Peirce for the opportunity to exercise her intellect and actively sourced texts to study (Somerville and Somerville, 1873, p. 356).

There are numerous other examples of Somerville soliciting mathematical texts from her contemporaries in this time of relative isolation.

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41 Whereas Hamilton introduced an algebraic system without commutativity in his quaternions, Peirce went one step further and proposed algebras for which division was not well-defined (Pycior, 1979), (Kent, 2005).

42 Spottiswoode had visited Somerville in Naples in 1869, so she was most likely aware of his interest in algebra. In fact Spottiswoode included Peirce's major results from his *Linear Associative Algebra* in his retirement address before the London Mathematical Society a year later in 1872 (Pycior, 1979). Spottiswoode mentions his visit to Naples in MS, Dep. c. 372, MSS–9, William Spottiswoode to Mary Somerville, 09/11/1869.

43 Spottiswoode explained why he chose to send the work of Tait rather than William Rowan Hamilton (often attributed with producing the earliest work on quaternions) by the following: "I have sent this rather than Sir William Hamilton's works as the latter are intolerably diffuse, & Tait has carried out the applications of the subject much further than anyone else." (MS, Dep. c. 372, MS–9, William Spottiswoode to Mary Somerville, 20/08/1871.) Nevertheless in 1871 Somerville requested John Murray III to send her a copy of Hamilton's *Quaternions*; she did not specify whether she wanted his 1866 *Elements of Quaternions* or the earlier *Lectures on Quaternions*, but only the latter is held in her collection of books (Rowan Hamilton, 1853), (Rowan Hamilton, 1866) (Girton College Library: Somerville Collection (073112).) It is thus very likely that it was either this or Tait's book on quaternions that Somerville was studying on the day that she passed away.

44 Girton College Library: Somerville Collection (073145) & (073146) & (073141) & (073142).

When visiting London in 1844, she turned to Augustus De Morgan for advice on books which showed "the recent progress of mathematics in England & France", and where she could find a copy of *Mathematical essays by the late William Spence* (Herschel, 1819).[45] It is possible that during discussions with Herschel on the subject of algebra, the latter gave her his copies of De Morgan's second and third papers on algebra, as De Morgan explains that Herschel had asked him to share with Somerville a copy of the first paper, but he had none to share. De Morgan instead directed Somerville to Peacock's forthcoming second volume of his *Treatise of Algebra*.[46] Four years later George Boole forwarded to Somerville some of his mathematical tracts on the calculus of logic, on the request of De Morgan, and as previously mentioned Somerville was listed as a recipient of the *Greenwich Observations* until at least 1859.[47] Somerville also seems to have taken an active interest in furthering the cause of astronomy more generally, above her own personal studies and interests. In 1848 she forwarded a paper to the Astronomer Royal, George Biddell Airy, in the hopes he would forward it to Thomas Maclear (1794–1879), who was then Her Majesty's Astronomer at the Cape of Good Hope, South Africa. The paper was by Sir William Morison (1781–1851), and according to the letter described a novel astronomical phenomenon which required further observations at the Cape Oservatory to be understood. Airy responded by returning the paper to Somerville, recommending that she send it to Herschel who would be better placed to advise Maclear on what should be done.[48]

An obvious limitation to Somerville's engagement is that she almost exclusively acted as an interested observer or supporter of mathematics; she doesn't appear to have written any new papers, or shared any novel results in her letters. It is therefore somewhat surprising that in the late 1860s she returned to work on the manuscripts she had written 30 years previously.

According to an early draft of PR, when departing for Rome in 1838 the Somervilles left their "cabinet of minerals, a valuable collection of original letters, and several manuscripts" in the care of Woronzow and his wife, Agnes. Somerville identified *Theory of Differences* and *Figure of Bodies* as having been in this collection, and wrote that she had "entirely forgotten [she] had written these manuscripts

45 MS, Dep. c. 370, MSD–3 123, De Morgan to Somerville, undated.

46 MS, Dep. c. 370, MSD–3 123, De Morgan to Somerville, undated. This is the letter the reverse of which includes a rather terse postscript regarding Somerville claiming that she did not know she was an honorary member of the RAS (see section 3.)

47 MS, Dep. c. 369, MSB–9 346, George Boole to Mary Somerville, 26/04/1848.

48 MS, Dep. c. 369, MSA–1 211, George Biddell Airy to Mary Somerville, 8/07/1848.

till they were brought to [her] at Spezia", in Italy (McMillan, 2001, pp. 185–6). Woronzow had sadly passed away in 1865, so it seems likely that these manuscripts and letters were sent on to Somerville soon after as they could no longer be stored at the house of her son and daughter-in-law.[49] Elsewhere in her drafts Somerville explicitly wrote of "heartily regretting" having ever written on the popular sciences, as her strengths lay in the calculus, and she should instead have made a new edition of the *Mechanism of the Heavens*.[50] A similar sentiment is repeated in the printed version where she described *Microscopic Science* as a mistake and mathematics as "the natural bent of [her] mind", conjecturing that had she devoted herself exclusively to her mathematical studies she "might probably have written something useful" (Somerville and Somerville, 1873, p. 338). Therefore, when reunited with her manuscripts perhaps a sense of nostalgia or regret prompted her to recommence her work on these texts.

The work required to complete and update these manuscripts was by no means trivial. In January of 1869 Martha Somerville reported to John Herschel that "My mother is very well & busy with mathematics — it is astonishing how much at home she is in these studies".[51] *On the Figure of the Celestial Bodies* bears evidence of extensive revisions, and remains in a state of extreme disarray. As the reader may have noticed from table 3 there is a substantial jump in the pagination after page 39. In fact, page 21 is followed by a page with two page numberings, one in pen matching the hand which numbered the preceding pages— giving the page as 26 — which was written over a pencil pagination which gives the page as 242. These concurrent numberings continue together until page 47 and 262 respectively, after which only the pencil pagination carries on. Thus although the page numbers run from 1 to 416, there are in fact only approximately 100 double-sided leaves in the manuscript. Unfortunately no other drafts or sheets remain in the collection, so it is impossible to know what material these missing pages contained, or at what point they were lost (or abandoned). Owing to the large gap since Somerville

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49 The mineral cabinet was offered to the British Museum in 1866 for £10: MS Dep. c. 371, MSM–3 192, Nevil Story Maskelyne to Mary Somerville, 25/07/1866. If the mineral collection was accepted by the British Museum it would most likely have been transferred to the Natural History Museum on its opening in 1881; owing to Covid-19 it has not yet been possible to verify the acquisition using the donor index cards. With thanks to Robin Hansen of the Natural History Museum and Francesca Hillier of the British Museum for this information.

50 MS Dep c. 355, MSAU-2 as quoted in (Neeley, 2001, pp. 189–190). Neeley notes that Somerville also expressed regrets for not spending more time painting and learning languages.

51 HS/16/325, 27/01/1869.

wrote the first version, a comparison of the handwriting makes it relatively easy to identify which passages were amended or added during these attempts at repair. In the late 1860s, when Somerville was in her eighties, her handwriting was visibly shakier, as can be seen from the handwriting samples shown in figures 24a, 24b, and 24c.[52]

The first 20 foolscap sheets were almost certainly composed in the 1860s. These sheets feature 16 hand drawn diagrams which have been pasted on to the sheets, most of which appear to be cut from a much earlier draft of the work, as they are drawn in a clear and steady hand (compare fig 25a with fig 25b). The numbering of the figures matches Somerville's hand from the 1860s, suggesting that they did not feature at the start of the previous draft, or have been reordered in the redrafting process. A further three sides inserted at page 342, four sides at page 358, and pages 415 and 416 — the final two of the extant manuscript — are in Somerville's later handwriting. The page numberings at page 342 are interrupted by the four inserted sheets, suggesting that they were numbered by Somerville before she made the addition.

Somerville was not merely revising these manuscripts for enjoyment, but had the intention of publishing them. Her intent to publish, at least in regards to *Theory of Differences*, is clear from the note written on the envelope cover in which she catalogued the manuscript (shown in figure 20) which reads as follows:

<div align="center">Theory of Differences</div>

> The Differential calculus & its application to points, curved lines, areas & solids in space with Diagrams, the partial differential equations being carried to the third order M.S.

> I think this MS must have been written as an exercise before or after the year [blank]. It is very perfect as far as it goes & might be published after my death. Naples, 13th August, 1869

That Somerville began preparing these manuscripts for publication at almost the same time she was writing her *Personal Recollections* is not a coincidence. After continuing financial troubles, in 1837 Somerville had successfully agitated, with the assistance of Charles Babbage and Robert Ferguson, to get an increase of £100 to her annual pension (Patterson, 1983, pp. 160–1). However, this pension was only

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52 Somerville commented on the change in her handwriting since the 1830s: "Now that my hand shakes like an aspen leaf, I wonder at the beauty of my writing and diagrams" (McMillan, 2001, p. 186).

(a) Letter from Mary Somerville to John Herschel 25/08/1863, held in the Royal Society HS/16/371.

(b) The first foolscap sheet of FOB.

(c) Page 271 of *On the Figure of the Celestial Bodies*, probably written in the 1830s.

Figure 24: Somerville's handwriting in an 1863 letter compared to manuscript sheets in FOB.
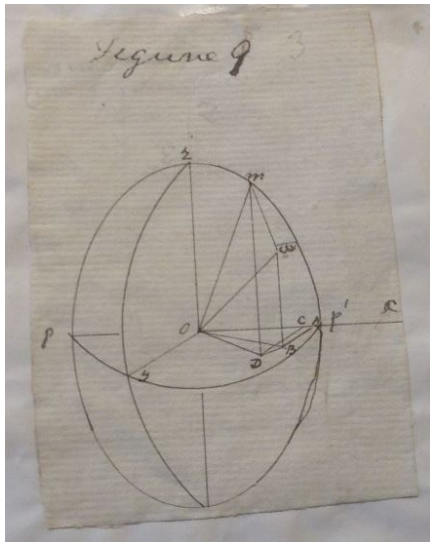
(a) Figure 9, page 7 of FOB.
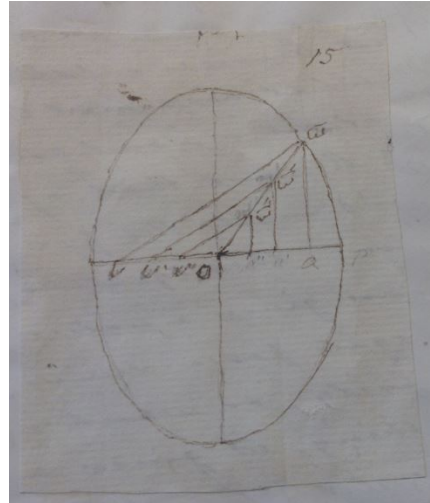
(b) Figure 15, page 17 of FOB.

Figure 25: Diagrams featured in FOB

payable to Somerville for as long as she lived, which left the question of how her two unmarried daughters would make a living after she and her husband died, as the family had no wealth to fall back on. As early as 1835 Somerville had tried and failed to get the pension continued to her daughters in the event of her death — perhaps motivated by Somerville's previous ill health which had prompted her stay in Paris in 1832 (Patterson, 1983, p. 171).[53] Considering the ongoing successful sales of *On the Connexion of the Physical Sciences* and *Physical Geography*, which had been reissued in 1858 and 1862 respectively, it makes sense that Somerville would have looked for other writing which she could publish in order to generate an income for her daughters. This may also explain Somerville's determination to see *Molecular and Microscopic Science* in print after it was criticized heavily by an anonymous 'scientific person', and why she frequently encouraged Murray to let her know as soon as new editions of her works would be required.[54] In 1869 she prepared a second edition of *Microscopic Science* which, together with the manuscript of *Personal Recollections*, she planned to leave with her daughters at her death.[55] That Somerville's interests here lay more in profit than furthering the cause of science is further supported by her comment on the manuscripts in the draft of PR — she wondered why they had been

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[53] Martha Somerville was later awarded a pension in her own name as the editor of Somerville's *Personal Recollections*, MS Dep. c. 370, MSD–3 127, Benjamin Disraeli (Earl of Beaconsfield) to Martha Charters Somerville, 18/05/1877.

[54] NLS MS 41131 23, Martha Charters Somerville to Joseph Pentland, 23/12 (no year).

[55] NLS MS 41131 197, Mary Somerville to John Murray III, 4/03/1870.

written at all and supposed "they were thought to be of no use at the time; I am sure they are of none now" (McMillan, 2001, p. 186).

That Somerville's publisher and friend, John Murray III, was entrusted with ensuring the financial stability of Somerville's daughters is suggested in a letter to him from Martha Charters Somerville, sometime between 1872 and 1875 (after the death of Mary Somerville, but before the death of her daughter Mary Charlotte Somerville). Martha wrote to assure Murray that she and Mary Charlotte were not in need of an advance of one or two hundred pounds which had been offered to them, but could wait until the next January to receive "the full amount".[56]

It was not until 1874, a year after PR was published, that Murray began moving forwards with his plans to publish the two mathematical manuscripts. At this time they were both sent to Thomas Archer Hirst who was then Director of Studies at the Royal Naval College, Greenwich, and President of the London Mathematical Society. Hirst was a sensible choice of reviewer as he was outwardly open to women participating in mathematics, having given in 1869 a series of twenty-four lectures on geometry to the Ladies Educational Association of London. In addition, he had met the two Somerville daughters whilst hiking in Switzerland the year before; he described them in his diary as "pleasant intelligent ladies, great admirers of Tyndall."[57] Hirst gave his assessment of the manuscripts in a letter addressed to 'John' (most likely John Murray III) as follows:

> Mrs Somerville's Treatise on the Calculus of Differences is a model of readiness and clearness of composition. Since it was written, however . . . [we] have penetrated deeper into the foundations of the calculus, and have perfected materially many of its methods. Except as illustrative of the character of the work of its accomplished author, the publication of this treatise now could scarcely be recommended & in short it has a biographical rather than a scientific interest. I read it, as I read her life, with the greatest pleasure.

> With respect to the second Work "on the forms of the celestial Bodies" I do not feel competent to express an opinion.[58]

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56 NLS, MS 41131, 33. As the letter is not dated, it is unclear which monies they are speaking about.

57 Thomas Archer Hirst, diary entry page 1892, August 10, 1873. John Tyndall (1820–1893), at that time Professor of Natural Philosophy at the Royal Institution.

58 MS, Dep. c. 370, MSH–5 331, Thomas Archer Hirst to 'John', 27/07/1874

Hirst went on to question the benefit that publishing these works would have on Somerville's reputation as a scientific writer, and suggested that were she to write the works anew she would have wanted to alter them materially.

It is evident that a biographical interest was not deemed sufficient to warrant their posthumous publication, and they were returned to the envelopes in which Somerville had placed them, where they remained unstudied for nearly 150 years.

5.5   CONCLUSION

Between 1832 and 1835 Somerville prepared three books for publication, all very different to each other but all can be situated within the move to reform British science and mathematics through the adoption of analysis. The first was *Connexion*, an expansion of her Preliminary Dissertation where she surveyed recent developments in the physical sciences without going into any of the mathematical details. Nevertheless the knowledge of nature and the universe which was detailed in the book was consistently attributed to the application of analysis, and the reader was encouraged to engage with mathematics in order to truly appreciate the beauty of the results. Once this book was drafted, Somerville began working on a second volume of her translation of *Mécanique Céleste*, to include omitted material such as that on the tides and the figure of the earth. Finally, Somerville completed an introductory text on the differential calculus, and its applications to the study of curves and surfaces.

The choice of which works were ultimately finished and published seems to have been highly influenced by monetary considerations, on behalf of the Somervilles as well as their publisher. Throughout the 1820s and 1830s the Somervilles suffered ill health and financial setbacks, and the extra money from book sales amounted to a much needed 10% increase in their annual income. Although Somerville received encouragement from influential mathematicians, such as Poisson, to write a second volume of her *Mécanique Céleste* translation, the limited commercial success of *Mechanism* rather suggested that a second volume would not be the 'popular' work that she desired to write. With the founding of new universities in London and the ongoing changes in the curriculum at Cambridge, there was the possibility of cashing in on the student market with a textbook on the calculus that would provide it with a rigorous foundation and fit it into a gentleman's liberal education. However, such a textbook written by someone without a university education themselves, and without the

necessary social contacts to ensure it would be used by the private tutors who exerted the most control over students' studies, would again not appear as the most lucrative project. In the end it was only the first of these works that was ever published, and in fact *Connexion* became one of Somerville's most successful books, selling over fifteen thousand copies in her lifetime.

Though mathematics faded from view in her published works, this by no means marked the end of her studies in the field. She continued participating in wide networks of mathematicians spread across Europe and North America, as both a consumer of knowledge and as an active agent furthering research (even if the research was not her own). Near the very end of her life, when reunited with her unpublished manuscripts, she again turned to mathematics as a way to provide for her family even after her own death.

Deemed to have no mathematical interest in the nineteenth century, these manuscripts certainly have a historical interest today. They offer a new window into the uncertainty and discord which continued to plague differential calculus well into the 1830s in Britain, and show Somerville as a critical reader of the French mathematical texts on which she built her reputation as an expert.

CONCLUSION

> In the climax of my great success, [by] the approbation of
> some of the first scientific men of the age and of the public
> in general I was highly gratified, but much less elated than
> might have been expected, for although I had recorded in
> a clear point of view some of the most refined and difficult
> analytical processes and astronomical discoveries, I was
> conscious that I had made no discovery myself, that I had
> no originality. I have perseverance and intelligence but no
> genius. That spark from heaven is not granted to the sex,
> we are of the earth, earthy, whether higher powers may
> be allotted to us in another state of existence, God knows,
> original genius in science at least is hopeless in this.
> (Somerville c.1872 as quoted in (McMillan, 2001, p. 145)).

This thesis presents the first exploration of Somerville qua mathe-
matician, expanding and elaborating the timeline of her mathemati-
cal activity, and her involvement in attempts to reform mathematics
in Britain. Somerville's journey of becoming and being a mathemati-
cian lasted throughout her long life of nearly ninety-two years, dur-
ing which time she faced many obstacles, from a lack of access to
education and books, to constraints on the types of publications she
could pursue. We considered here both her central position within
the wider British mathematical community, and the specificities of
the path she took to be one of the most famous mathematical women
of the nineteenth century.

A key factor to her success was certainly her ability to dexterously
navigate polite society and build social connections with the most
influential scientists and mathematicians of the day. Whilst a young
girl of the middle classes in Edinburgh she frequently attended soci-
ety functions, such as the theatre or dances, earning herself the title
'the Rose of Jedwood'. Rather than as a university student, it was in
the drawing rooms of Edinburgh where she became acquainted with
the professor of mathematics, John Playfair; it was most likely Playfair
who then introduced her to her future mentors, the Wallace brothers.

The ways in which Somerville could interact with polite society
drastically changed on her marriage to William Somerville. Whereas
in Burntisland she had been a widow and mother living by the hos-

pitality of her parents, with William Somerville she became the lady of the house, and was able to chaperone others rather than being dependent on a chaperone herself. Moreover, William actively interested himself in the fashionable learned societies and gentlemen's clubs of the day, gaining memberships of the Royal Societies of Edinburgh and London, acting as a Manager of the Royal Institution, and helping to found the Athenaeum Club. Through William, Somerville gained easy access to the resources, if not the buildings, of these institutions which, except for the RI, were closed to women. She was also able to expand her network of correspondents and acquaintances throughout Western Europe, which would be vital for her future published works. Crucially, the mediation carried out by William was not as a gatekeeper, as is so often the case with women who were dependent on a male relative to engage with scientific activity, but as a willing and supportive assistant. Somerville was by no means a shadowy figure, passing off her knowledge as her husband's, but a proficient conversationalist who almost seamlessly participated in the informal exchange of knowledge in a community made up of 'Grand Amateurs' (as characterised by (Chapman, 2015)).

On moving to Italy in 1838, Somerville continued to use what might nowadays be termed her 'networking' skills to ensure that she retained access both to books and the upcoming experts writing them — many of the colleagues she first made in the 1810s and -20s having since passed away. Her correspondents sent her works directly, gifting her books or sharing offprints of their papers, informed her where journals or resources could be found, or indeed sent astronomers and natural philosophers her way furnished with letters of introduction. That Somerville continued to command respect and attention in society until the very end of her life is evidenced by the many men and women from across Europe and the USA who paid her a call when travelling in Italy.

Following in a long tradition of women making names for themselves through participation in emerging scientific fields, Somerville's success hinged on her facility in so-called "French analysis", which was seen by many as the solution to the decline of British mathematics. By far the main reason for which she has been remembered and celebrated as a mathematician is her 1831 book *Mechanism of the Heavens*, a translation of Laplace's analytical treatment of celestial mechanics which built directly on the work of Newton. That she was commissioned to write this book, clearly shows that she was known as an authority on the work of Laplace long before it was published,

and in fact her interest in mathematics as practiced on the continent goes back as early as 1812.

The archival record of Somerville's engagement with mathematics before her second marriage is very slim, so perhaps all we will ever know of this time is what she could recall in the writing of her *Personal Recollections*.[1] However, it is notable that the earliest letter we have written by Somerville which contains mathematics, written just before her wedding to William, should show her attempts at using differential calculus to solve a problem.

By demonstrating her interest in and aptitude for differential calculus, Somerville was able to recruit William Wallace as her mentor. Wallace had used differential calculus in his own work in a 'revolutionary spirit' and was heavily involved in the *New Series of the Mathematical Repository*, a key vector for the circulation of French mathematics in Britain in the early nineteenth century. Wallace guided Somerville's studies towards analytical texts, most of which were written in France. He also introduced her to other mathematicians who wished for a reform in British mathematics, including John Herschel who would later assist Somerville during the preparation of her Laplace translation. With feedback from Wallace on her attempted solutions to mathematical problems Somerville was able to develop her competency in methods of differentiation and integration which would have been invaluable for gaining an understanding of Laplace's *Mécanique Céleste*; an understanding she clearly had by 1817 when she met Laplace in Paris, and left him with the impression that she was one of the most enlightened judges of his work. Moreover, by submitting solutions to the *Repository*, in which she used these methods, Somerville herself contributed to their visibility.

After a series of financial setbacks alongside bouts of ill health, in the 1830s Somerville turned to book-writing as a way to supplement her family's income and provide for her two unmarried daughters. Initially intended for the general readership of the Society for the Diffusion of Useful Knowledge, *Mechanism* was in fact a dense and highly algebraic work entirely unsuitable for readers who had not studied mathematics to a high level. Nonetheless it acted as a symbol of what could be achieved by an auto-didact with perseverance and determination, and brought the newest results in physical astronomy to wider attention. In the end the book appears to have made Somerville and her publisher John Murray only a modest profit from

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1 In contrast, this thesis demonstrates that the collection of her later correspondence and papers is a rich resource offering a deep insight into the scientific community of the nineteenth-century, and Somerville's central place within it.

sales. Although she retained her interest in advocating for the importance of studying analytical mathematics, Somerville was determined her next work would be more 'popular'. She prepared three manuscripts: a survey of recent scientific developments that used analytical methods; a second volume of *Mechanism*; and an introductory pedagogical text on the differential calculus. In the end it was only the first of these that was deemed likely to have good sales, and the other two manuscripts were bundled up and in 1838 left with her other papers at the home of her son.

Reflecting back on her long life, Somerville felt that it was mathematics which had brought her the greatest joy. When reunited with her unpublished manuscripts in the late 1860s she picked up where she had left off, and again began preparing them for possible publication, expected to be after her death. Having been written by someone who was seen by the mathematical community as an expert in differential calculus, the pedagogical text *Theory of Differences* clearly demonstrates the ongoing uncertainty around how to rigorously understand limits, series, and infinitesimals in the 1830s. However, by 1860 the mathematical community had moved on to other questions, and the manuscripts were both left unpublished. Somerville herself believed that mathematics had by that time entered a new even more powerful era with William Rowan Hamilton's quaternions (Somerville and Somerville, 1873, pp. 182, 338).

Somerville does not easily fit into a narrative of genius, creativity, or originality, as is so often constructed to justify researching a woman in science. Nevertheless this was certainly a criteria on which she was judged by her contemporaries, and, as shown by the quote at the top of the conclusion, by which she judged herself.

In his review of *Connexion* William Whewell tied himself in knots trying to explain away how Somerville had overcome the limitations of the fairer sex to achieve a deep knowledge of mathematics and the physical sciences. He argued that "notwithstanding all the dreams of theorists, there is a sex in minds. One of the characteristics of the female intellect is a clearness of perception... when women are philosophers, they are likely to be lucid ones... if they attain to the merit of being profound, they will add to this the great excellence of being also clear" (Whewell, 1834, pp. 65–66).[2] (Un)fortunately, women philosophers were incredibly rare, and indeed Whewell only admitted two others "worthy of entirely honourable notice" — Hypatia and Maria Gaetana Agnesi, with Emilie du Châtelet discounted for her dishonourable conduct (Whewell, 1834, p. 66). Yet, for all his praise of the

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2 See also (Neeley, 2001, p. 14).

lucidity and importance of her work, Whewell still could not find a place for Somerville in his *History of the Inductive Sciences* as he only concerned himself with what he considered to be original discoveries, of which Somerville had apparently made none (Whewell, 1837), (Todhunter, 1876, Vol 2, 260).

For all the different types of work that were necessary to produce scientific knowledge, the illusive 'original discovery' was by far the most valued and prestigious. In his own review of *Connexion*, David Brewster urged Somerville to use her "great mathematical acquirements...and profound knowledge of the principles of physical science" for "original investigation" (as quoted in (Neeley, 2001, p. 123)). Thirty-five years later when arguing against the inferiority of women's intellect in his essay on 'The Subjection of Women', John Stuart Mill claimed that "Mrs Somerville, alone perhaps of women, [knew] as much of mathematics as [was] needful for making any considerable mathematical discovery" (Ryan, 1997, p. 189). He saw it as an indictment on the state of women's education and place in society that Somerville had not managed to make a name for herself with a "striking advancement" in mathematics.

Although it would be a stretch to ascribe Somerville with groundbreaking genius — alas she didn't use epsilontics twenty years before Weierstrass, nor secretly solve the three body problem — her work was doubtlessly collaborative and productive. Before publishing *Mechanism*, Somerville debated and discussed emerging work in physical astronomy and analysis with her scientific contemporaries, as reflected in her correspondence and in the occasional references given in her book. Neither of the two most mathematically conversant reviewers expected Somerville to insert original or novel ideas into her translation of Laplace, but instead looked at the selection and arrangement of materials and whether they coalesced to form a clear explanation of the methods and results at hand. Despite the fact that *Mechanism* displayed very little "inventive power", Charles Lyell nonetheless felt that the state should award her £5,000 for the benefit conferred by a woman who could teach mathematicians, who he described as "the most overbearing of all aristocracies" (Lyell, 1881, p. 171).

Her second book, *On the Connexion of the Physical Sciences*, was identified by James Clerk Maxwell as a "suggestive book" which presented "guiding ideas" in an intelligible and communicable form in order to lead men of science to new discoveries (Secord, 2014, p. 108). *Connexion* sold over seventeen thousand copies in total, and was very widely read. Mineralogist Nevil Story Maskelyne won a

copy of the work whilst still a grammar school student and described himself to Somerville as "very truly one of your many pupils", whilst Robert Barclay Fox studied it in his schoolroom alongside his sisters (Brett, 1979, p. 723).[3] Indicating how many other young ladies may have studied the work is Thackeray's *Vanity Fair*, where he described a group of women as "very blue and well informed; reading Mrs Somerville, and frequenting the Royal Institution" (Thackeray, 1848, p. 555).

Certainly one of the most suggestive passages in *Connexion* was that the inability of astronomers to accurately compute tables of motion for the planet Uranus was owing to disturbances from another unknown celestial body. This passage was included at least as early as the fifth edition in 1840, in which Somerville went on to suggest that "the motions of Uranus. . . may reveal the existence, nay even the mass and orbit of a body" that was as yet unknown and unobserved (Somerville, 1840, p. 74). Although she was likely still receiving the *Greenwich Observations* at this time, which contained the necessary astronomical data, there is unfortunately no evidence that Somerville herself tried to compute the mass or orbit of the conjectured planet.

However, when spending Christmas with John Couch Adams at the Herschels in 1848, Adams supposedly told William Somerville that it was a passage in *Connexion* which had inspired him to calculate the orbit of the body that was disturbing Uranus (Somerville and Somerville, 1873, p. 290).[4] A year later, when preparing the eighth edition of *Connexion*, Somerville informed her publisher that she wished to include the new planet's discovery as her "vanity [was] concerned with regard to Neptune for [she had] predicted its discovery and should be sorry not to tell of its fulfillment[sic]".[5]

In his account of the discovery of the planet that would subsequently be named Neptune, Airy included extracts from letters written by astronomers and mathematicians across Britain and France. He clearly demonstrated the urgency felt in the scientific community to resolve the inadequacy of the tables of motion for Uranus, which was ultimately done through locating and observing a new, exterior planet. Indeed, Airy felt that the discovery was a result of "the feeling of the scientific world in general", and of "a movement of the age" (Airy, 1846). Although her contribution to the discovery of Neptune

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3 MS Dep. c. 371, MSM–3 192, Nevil Story Maskelyne to Mary Somerville, 25/07/1866.
4 Adams was part of a priority dispute with Urbain Le Verrier regarding the discovery of Neptune in 1846.
5 NLS, MS 41131, 93, Mary Somerville to John Murray III, 1/01/1849. Somerville included this information in (Somerville, 1849, pp. 69–71).

was indirect, Somerville was nonetheless an active participant in this movement.

What is abundantly evident is that, original or not, Somerville was respected and appreciated as a mathematician by the scientific communities of which she was a part. Numerous glass ceilings were cracked by the force of her reputation: professors loaned books from their university libraries on her behalf, even if she was unwelcome as a student; her work was published in the transactions of learned societies of which she was ineligible for membership; and in honour of her translation of Laplace she was able to sit in the meeting room of the Royal Society of London, albeit only as a marble bust. Mathematics as a research discipline is intensely collaborative, and this is born out in Somerville's correspondence. From critical discussions of recently or soon-to-be published works to the sharing of astronomical data, her opinions and interpretations were sought after and valued. Crucially, Somerville was seen not just as an exceptional mathematician for a woman, but as an authority in analysis, an area of mathematics that few others could understand.

A

PUZZLE QUESTIONS FROM THE *MATHEMATICAL REPOSITORY*

A.1 *mathematical repository* QUESTIONS SOLVED BY 'A LADY' IN VOLUME 3, 1814

All solutions published under the pseudonym 'a Lady', in Volumes 3 and 4 of MR, can be found in Volume 1 of Somerville's Collected Works, edited by James Secord (Secord, 2004, 1, Part 1, I.1–I.5).

XX. PRIZE QUESTION 310, *by* Mr. W. Wallace.

Find such integer values of x, y, z as shall render the three expressions $x^2 + axy + y^2$, $x^2 + a'xz + z^2$, $y^2 + a''yz + z^2$ squares, a, a', a'' being given numbers.

First solution, by a Lady. Second solution, by Mr. Lowry.

I. QUESTION 311, *by* Mr. John Hynes, *Dublin*.

To divide a given square number n^2, into two such parts that the sum of their squares and the sum of their cubes may both be rational squares.

First solution, by a Lady. Second solution, by Mr. Cunliffe, R. M. College. Third solution, by Mr. Lowry, R. M. College.

XIV. QUESTION 317, *by* G. V.[1]

Let ABCD be a parallelogram, draw the diagonal BC, and draw DE perpendicular to BC; then, perpendiculars drawn to AB, AC at the points B and C shall intersect each other in the line DE. Required the demonstration?

First solution, by Mr. John Dawes, Birmingham. Second solution, by Eratosthenes. Ingenious demonstrations were received from Messrs. Adams, Baines, and a Lady.

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1 G. V. was a pseudonym of William Wallace (Craik, 1999, p. 245).

A.2   *mathematical repository* QUESTIONS SOLVED BY 'A LADY' IN
      VOLUME 4, 1819

VII. QUESTION 377, *by* Mr. Cunliffe.

What is the relation of the diameters of the three circles,
passing through the extremities of the sides, and point of
intersection of the perpendiculars from the angles upon
the sides of a plane triangle?

First solution, by a Lady. Second solution, by Mr. Cunliffe, the Pro-
poser.

XI. QUESTION 381, *by* Palaba.

The equation to the lemniscata being $(x^2 + y^2)^2 = x^2 - y^2$;
find its area contained between the values of $x = 0$ and
$= 1$.

First solution, by a Lady. Second solution, by Palaba, the Proposer.

XII. QUESTION 382, *by* Palaba.

Determine that point in a curve whose equation is $a^{n-1}x =
y^n$ to which a line must be drawn from the vertex making
the greatest angle with the curve.

First solution, by a Lady. Second solution, by Palaba, the Proposer.

A.3   REMAINING *mathematical repository* QUESTIONS SOLVED BY
      MARY SOMERVILLE IN HER NOTEBOOK

The following questions were all published in Volume 4 of the *New
Series of the Mathematical Repository*, 1819.

II. QUESTION 332, *by* Mr John Hynes.

To find two fractions such that the sum and sum of their
squares shall both be rational squares; and either of them
being added to the square of the other shall make the
same square.

Solution by Mr Cunliffe.

XIV. QUESTION 384, *by* Palaba

Find the equation of the curve of which this is the prop-
erty: if from a fixed point in the axis a perpendicular be

drawn to it and produced to meet a tangent to any point in the curve, the length of this perpendicular and tangent together, shall be double the length of the curve between the vertex and the point from which the tangent was drawn.

First Solution, by Palaba, the Proposer. Second solution, by Mr. W. Wallace, R. M. College.

XVII. QUESTION 387, *by* Palaba

TB, BC are the subtangent and ordinate of a curve whose vertex is A, and the tangent of the angle TCA is the tangent of the angle ACB in a given ratio. What is the nature of the curve?

Solution by Palaba, the Proposer.

SOMERVILLE-WILLIAM WALLACE
CORRESPONDENCE

The following letters are held in MS Dep. c. 372, MSW–1.

[folio 160]
R. M. College 12$^{\text{th}}$ May 1816

Dear Madam,

In looking over the solution of the 14$^{\text{th}}$ Question of the 14$^{\text{th}}$ N$^{\text{o}}$ of the Mathematical Repository I observe you apply a formula for any arc of a curve which I have given in art 77 of Fluxions of the Edin[burgh] Encyclopaedia. There is however a circumstance which I believe you have overlooked. In the formula to which I refer, the point A (see page 18. Fluxions) from which the perpendiculars are drawn is a <u>given</u> point, ~~that~~ or is the same for every point of the curve: But in the problem under consideration (see your figure) the point A is <u>variable</u>, in which case it does not hold true that $EP = T - \frac{\partial p}{\partial u}$ &c. Owing to this circumstance I believe the mode of calculation will not apply.

I have been led to consider the problem and have found a solution which I intended to send with this letter, but wishing to polish it and to revise the calculations I have not been able to get it ready to [illegible] the post. I hardly ever resolved a problem in the most direct manner possible at first: In general I find that a first solution may be improved and shortened, hence it always happens that a short and simple solution is the result of long meditation.

The other two solutions I believe are correct and Elegant. I ~~think~~ presume the expressions in the problem respecting the area of the Lemniscata might be made on appearance more simple by writing $\cos 2\phi$ instead of $\cos^2 \phi - \sin^2 \psi$ and $\sin 2\phi$ for $2\cos \phi \sin \phi$. I shall now look at with more attention.

I send you two exercises on the application of analysis to geometry. I shall send you in a short time the solutions sealed up, that you may open them, only ~~open them~~ when you have made a trial to resolve them & wish to compare them with your own solutions: unless

you do wish to spend longer time in seeking to resolve them. The difficulty consists in finding the analytical demonstration of known truths.

I am now beginning to hope that my daughters are rather not quite so ill as when I saw you. I wrote to Dr Somerville yesterday or the day before & I presume he mentioned to you the reason why we laid aside the intention of bringing them to town. They cannot yet be moved & we look with anxiety for their amendment.

<div style="text-align: right">

I remain Dear Madam

Your most obed[ient] Serv[ant]

W. Wallace

</div>

<div style="text-align: right">

[folio 161]

R. M. College May 18$^{\text{th}}$ 1816

</div>

My dear Madam,

I feel sensibly the sympathy manifested in your friendly letter of Tuesday last. I fear I was too sanguine in my hopes when I last wrote to you. I am sorry to say that in the case of my eldest daughter very little amendment has taken place and the only consolation is I have that she does not appear to be worse. Her sister is greatly better and in all probability will soon be well.

I here enclose the solution which you put into my hands. I ought to have sent it with my last letter but in my hurry I forgot it.

I likewise enclose a solution of mine to the curve problem. If you wish to try again to resolve the problem I recommend you not to look into my solution until you have made your own. At least, ~~I know~~ this is the way I commonly proceed. The one I send you is the best of two I have found. I recommend to you to avoid angular functions and to employ in your solution only the coordinates x, y and the arc z and constant quantities. Of course you may with convenience put a symbol p for $\frac{\partial y}{\partial x}$, as you will find that the problem requires two integrations. And that you may know when you are right I here put down the figure of the curve and its equation.

BC is the axis, A the given part, AF the perpendicular, PD a tangent at P, PQ an ordinate.

Make BC = 3BA, then, the property of having PD + DA = 2PB belongs to a curve of which this is the equation $3BC \times PQ^2 = BQ \times QC^2$.

I am much pleased with your solution of the first exercise I sent you. I here enclose a solution different, but not better from a work published periodically in France for several years past: Annales de Mathematiques . I think such exercises useful to prepare for the study of analytical works. I here send you various other exercises, and remain,

Dear Madam,
Your most obed[ient] serv[ant].
W. Wallace

P.s. Be so good as [to] give my best Respects to Dr Somerville.

[folio 162]
6 Lauriston Lane Edinburgh
23rd Dec[ember] 1831

Dear Madam

I have received the Copy of your Mechanism of the Heavens and I feel much satisfaction in contemplating the great Feat which you have accomplished. I can hardly hope that your example will be generally imitated by the Ladies but I believe you have proved beyond all question that at least one Lady has been able to do what few men have had the boldness to attempt to perform.

I believe Madam you have rendered an important service to Science by shewing that what many would reckon a hopeless task may yet be accomplished by patience and perseverance and perhaps some may discover from your book that the mathematical Sciences are not so arid as they had supposed them.

Most sincerely then do I congratulate you on the completion of your Sublime labour and may you long enjoy your triumph.

I have laid the Mechanism of the Heavens on my table with a sincere intention to read it and likewise that it may serve as a Monitor to inate me to exertion.

I was never an absolute believer in your friend Mr Babbage's Theory that Science is on the Decline in Britain, your Book certainly gives it no support.

I beg you will present my best respects to Dr Somerville I would almost write him a separate letter of congratulation on the position in which he stands but as he is likely to have enough that at present I shall defer saying more until I have the pleasure of seeing him.

I have the honour to be

Your most obed[ient] serv
William Wallace

[Addressed to Mrs Somerville, Royal Hospital Chelsea, London]

LETTER FROM JOHN ELLIOT DRINKWATER BETHUNE, ON A TITLE FOR SOMERVILLE'S TREATMENT OF LAPLACE

[MS, Dep. c. 370, MSD–4 134, John Elliot Drinkwater Bethune to Mary Somerville, 29/07/1831.]

My dear Mrs Somerville,

I lose not a moment in profiting by your permission to send you my handywork, and beg you to believe that I wished long ago to offer you this slight mark of my respect, but doubted whether I had a right to advance such a pretension to intimacy.

It was therefore with [illegible] that I seized the opportunity you yesterday gave me. I am fortunate in being able to say that I know the copy I send you has one <u>sure</u> merit, being one of a limited number (50) which the Society allowed me for my private friends.

I took the liberty of thinking upon your title as I walked home yesterday and now take the still greater one of offering you the result of my cogitations. If none of them strike your fancy, it may still be satisfactory to you to know that other people have thought on the subject without hitting on any title which you like so well as the one you determine on adopting. Those I have to propose are as follows:

1. Mechanical Principles of Astronomy

2. Mechanism of Astronomy

3. Mechanism of the Heavens

4. Mechanism of the Planets

5. Mechanism of the Heavenly Bodies
   ~~6. Of these I rather think Mechanism of the Planetary Motions~~

6. Mechanism of the Planetary Movements.

I think (3) the neatest and most striking of this set: my simple objection to it may not strike you perhaps very forcibly but I should have wished not to join a Greek word <u>Mechanism</u> with a Germanic word <u>Heavens</u>. After (3), come (6) in my estimation: (1) is perhaps less subject to criticism than any of the others: (2) is objectionable because

Astronomy includes within itself to a certain extent the <u>ism</u>. It should therefore be 'Mechanism of the Stars' & not 'Mechanism of the Starry Laws'. (4) & (5) are alike for good & evil: both may perhaps appear to relate rather to the internal constitution of each planet than to their relations to each other which same argument is in favour of (3). If (6) be adopted, there ought perhaps to be nothing of internal structure as "Figure of the Earth" which therefore makes it objectionable. I give my vote for (3) which is also very near Laplace's without being exactly a translation.

While I was still thinking on the matter I met Mr Brougham at the Athenaeum with Mr Peacock & in the course of a conversation about "everything in the world" Brougham recommended Politicoeconomical Principles of Astronomy.

I told him he was not so far out as perhaps he might think in recommending this, for in fact it is the political economy of the planet that you have to deal with, extending that term from the miserable meaning of "Production & Distribution of Wealth" to what I take it really to mean "the Service of Social Life". The planets to be sure, happy creatures! have neither corn laws nor game laws nor poor laws, for aught that we know: although while I write, it occurs to me as possible that there may be some hospitals kept in some out of the way corner of the Universe for all the little asteroids who get injuries when any of their bigger neighbours dash against each other, so as to be able to run round with the rest. I hope you will have a chapter devoted to this subject. Pray excuse all this nonsense

& believe me

Yours very sincerely

J E Drinkwater.

1 Garden Court

29 July 1831

SOMERVILLE-JOHN HERSCHEL
CORRESPONDENCE CONCERNING MECHANISM
OF THE HEAVENS

The following letters are from the Herschel Papers held at the Royal Society unless otherwise stated. Folio numbers are given at the start of each letter.

HS/16/327

R. H. Chelsea
March 31$_{st}$ [postmarked 1829]

My dear Sir

I esteem it a very great mark of friendship that you should donate any of your time to my paper which would be so much more agreeably spent with your fair and charming Bride; and to her also I owe many apologies for intruding at such a moment.

I am truly obliged to you for your criticisms which are perfectly just you may be assured that I shall gladly adopt every thing you may suggest. I beg you will take what time you please as I have sufficient employment in going on with the second book. —

It will be my pride to consider your wife as my friend and I trust to your giving us early notice of your return to London that you may spend a quiet day with us at Chelsea to make us acquainted. None of your friends rejoice more sincerely in your happiness than Dr Somerville and myself. we[sic] write in offering Mrs Herschel and you our kindest and best wishes.

Yours my dear Sir
very sincerely
Mary Somerville

[Addressed to J. F. W. Herschel Esquire, Leamington, Warwick]

HS/16/328

Oct[ober] 1829

My dear Sir

If you will have the goodness to send me the last 8 or 10 sheets of my MMS together with the one I sent you the other day I think I can both make an improvement and save you some trouble. Mr Richards comes to town on Thursday morn and will take charge of them with every kind wish to Mrs Herschel believe me truly y[ou]rs

M. Somerville

Monday

[Addressed to John W. F. Herschel Esquire, Slough, Windsor]

MS Dep. c. 370 MSH–3 310

My dear Madam,

I have just got your note with the integration of the equation in terms of r by indeterminate coefficients at present I see nothing to object against it, but shall read it more carefully with the context.

I have at lengths sent an end to a work which (though not much in itself) yet gave me a great deal of trouble, much more so than when I entered on it I could have imagined possible. It is an essay on <u>sound</u> as a companion to the work on Light of which you have a copy, as I mean you shall of its fellow — as soon as it appears. [illegible] have now in great measure completed the more troublesome part of the reduction of my sweeps, which hung upon me like an incubus, and stung my conscience whenever I thought of it — a little energy however has sufficed to see me nearly free from the worst of bondages — astronomical reductions accumulated on hand! The first result will be speedily I hope in your hands in the shape of a catalogue of about a thousand or 1500 more double stars [illegible] measured with the 20 feet, since June 1828.

I shall now be able to bestow my undivided attention on your work which hitherto I have found it impossible to do, though I have often begun it and as often been forced to desist. To you who knows what it is to <u>write</u> such a work I need offer little excuse for the delay. As it is not to be written <u>currente calamo</u> so it is not to be read by one who <u>runs</u> and reads. Indeed to be very candid with you, I <u>cannot</u>

pretend to read the whole of it — there will be parts, very large ones, on which I cannot give an opinion.

You and Dr S will be happy to hear that my mother continues steadily [illegible] in health. Her constitution is wonderfully vigorous, and though it has maintained a fearful struggle I yet trust that much of her strength remains unsubdued. I have taken a very nice comfortable house for her in Windsor and in some ten days or a fortnight I hope once more to do have her near me. She & Mrs Herschel join in kind regards to yourself & Dr S and I remain

<div style="text-align:right">

Dear Madam
yours very truly
J F W Herschel

</div>

[Addressed to Mrs Somerville, Chelsea College]

HS/16/329
(This letter was partially reprinted in (Somerville and Somerville, 1873, pp. 168–170); material in italics was omitted in the publication.)

<div style="text-align:right">

Slough. Feb[ruary] 23 1830.

</div>

My dear Madam.

I send you for Mr Richards the first 40 pages of your MS. I have here and there appended some pencil notes which you can easily rub out, and I take the opportunity here to make one or two remarks not so well inscribable in the blank pages, and of a more general nature.

As you contemplate separate publication, and as the attention of many will be found to a work from your pen for those who will just possess quantum enough of mathematical knowledge to be able to read the first chapter without being able to follow you into its applications, and as as these moreover are the very people who will think themselves privileged to criticise & use their privilege with the least discretion, I cannot recommend too much clearness, fullness & order in the exposé of the principles. Were I you I would devote to this first part at least double the space you have done. Your familiarity with the results and the formulae has led you into what is definitely natural in such a case — a somewhat hasty passing over what to a beginner would prove insuperable difficulties, and if I may so express it, a sketchiness of outline (as a painter you will understand my meaning & what is of more consequence, see how it is to be remedied).

You have adopted I see, the principle of virtual velocity, and the principle of D'Alembert, rather as separate & independent <u>principles</u> to be used as instruments of investigation than as convenient theories, flowing them selves from the general law of force & equilibrium, to be first <u>proved</u> and then remembered as compact statements in a form fit for use. The demonstration of the principle of virtual velocities is so easy & direct in Laplace that I cannot imagine anything capable of rendering it plainer than he has done. But a good deal more explanation of what <u>is</u> virtual velocity, &c., would be advantageous — and virtual velocities should be kept quite distinct from the arbitrary variations represented by the sign δ.

With regard to the <u>principle of D'Alembert</u> — take my advice and explode it altogether. It is the most awkward and involved statement of a plain dynamical equation that ever puzzled students. I speak feelingly and with a sense of irritation at the whirls & vortices it used to cause in my poor head when first I entered on this subject in my days of studentship. I know not a single case where its application does not create obscurity — nay <u>doubt</u>. Nor can a case ever occur where any such principle is called for. The general law that the change of motion is proportional to the moving force & takes place in its direction, provided we take care always to regard the <u>reaction</u> of curves, surfaces, obstacles, &c., as so many real moving forces of (for a time) unknown, magnitude, will always help us out of any dynamical scrape we may get into. Laplace, page 20, Mec. Cel. art 7. is a little obscure here, and in deriving his equation (f) a page of explanation would be well bestowed.

One thing let me recommend, if you use as <u>principles</u> either this, or that of virtual velocities or any other, state them broadly & in general terms. *See Mec. Cel. p12. "Si l'on fait varier infiniment peu &c". Indeed a little more distinctness ~~of~~ in the enunciation of theorems in their detached, insulated form, ready for any applications, will be desirable throughout.*

Allow me too to observe that you might take for granted that your reader understand a good deal of algebra, & geometry, &c. In Consequence, were I to advise, I should dispense with all those papers where <u>very</u> elementary abstract properties, and <u>very</u> common methods are stated. such as the passages I have marked in pages 21, 17, 19, &c.

In page 32 I confess I do not apprehend the connexion of the analysis. & in the equation

$$\{P - \frac{\partial^2 x}{\partial t^2}\}\delta x + \{Q - \frac{\partial^2 y}{\partial t^2}\}\delta y + \{R - \frac{\partial^2 z}{\partial t^2}\}\delta z - \lambda\delta u = 0$$

is <u>not</u>, as you make it, the reaction of the surface. That reaction is really

$$\lambda \times \sqrt{(\frac{du}{dx})^2 + (\frac{du}{dy})^2 + (\frac{du}{dz})^2}$$

and your equation (13) as it stands, is assumed, & not proved. The analytical artifice by which the addition of the term $-\lambda\delta u$ *added to the general equation, where* λ *is an indeterminate, render it equivalent to the two* $(P - \frac{\partial^2 x}{\partial t^2}\delta x + \&c = 0$ *and* $\delta u = 0$ *is too beautiful and too useful in all similar cases not to merit a distinct explanation, and in fact, without much circumlocution I do not see how its use is to be avoided.*

You will think me, I fear, a rough critic, but I think of Horace's good critic Fiet Aristarchus, nec dicet, cur ego amicum, Offendam in nugis? Hæ nugæ seria ducent, In mala, — and what we can both now laugh at, & you may, if you like, burn as nonsense — (I mean these remarks) — would come with a very different kind of force from some sneering reviewer in the plenitude of his triumph at the detection of a slip of the pen or one of those little inaccuracies which humana parum cavit natura.

I think you would find a regular system of numbering the paragraphs (each paragraph to be numbered as it begins on a fresh line in a page) extremely convenient for reference. I find such an aid invaluable.

Mrs Herschel desires her kind regards, & I remain dear madam

<div style="text-align: right">

Very faithfully yours,

J. F. W. Herschel.

</div>

[Addressed Mrs Somerville]

HS/16/330

<div style="text-align: right">

[Postmarked 1/3/1830]

R. H. Chelsea

1st March

</div>

My dear Sir,

I beg you will accept of my very sincere thanks for your criticism which is as just as it is friendly — I entirely concur with you in the importance of laying down the first principles with precision and clearness, and am well aware that an introduction intended for a short paper will not answer for a more voluminous work. It shall be my endeavour to fill out the outline so as to make it a distinct and perspicuous one instead of a sketch. I have only to entreat that you will

not scruple to give me work, for it is my ambition to spare no pains to acquit myself of so bald an undertaking without reproach.

I hope Lady Herschel is gaining strength. With every kind regard to Mrs Herschel & yourself

Believe me ever
Sincerely yours
M. Somerville

[Addressed to J. F. W. Herschel Esq., Slough]

HS/16/331

My dear Sir,

I do not know what to say in apology for sending the first few sheets to you again, but I really should feel uneasy without your opinion as to the changes I have made. I think it is now more consistent, and regular, perhaps I have omitted some things that ought to have been inserted, and probably have not sufficiently explained the more obscure passages — others I may have misapprehended. at all events your opinion would be invaluable and I shall write it again with pleasure should you think it necessary.

Having altered the arrangement of these sheets it may be necessary to make some change in that respect in those that remain for to say the [illegible] I forget how they stand having been long engaged with the application. I have finished the moon and satellites which completes what I intended, but whether the whole or any part ever goes to the press will depend on your advice which I know will be given with the truth of a friend and for which I never can be sufficiently thankful.

With every kind wish to Mrs Herschel believe me ever

truly yours
M. Somerville

6th March

[Addressed J. W. F. Herschel Esq.]

HS/16/332

<div align="right">Slough Mar[ch] 9 1830</div>

Dear Madam,

I lose not a moment in forwarding you a work I have just received from the author. It is a translation of the Mecanique celeste with a running comment, by (apparently) an able hand. How far its appearance at this junction may influence your views, I am of course incapable of judging but it is a <u>matter of fact</u> which you cannot be too early in possession of. I received your packet by Mr Richards. You are indefatigable, & the retouching you have given it has been most effective. Still I am not quite satisfied about the way in which the fundamental equation

$$\delta x\{Pdt - \frac{d^2x}{dt}\} + \delta y\{Qdt - \frac{d^2y}{dt}\} + \delta z\{Rdt - \frac{d^2z}{dt}\} = 0$$

is derived. Laplace is ingeniously obscure here, he regards the <u>Force</u> acting on a body in motion, <u>not</u>, as expended in producing its effect, ie motion — <u>but</u> as transferred into the moving body & accumulated in it in the shape of momentum which, in asmuch as it is an <u>affect</u> in the body to proceed forward & if opposed, to displace an obstacle, may be regarded as a moving force capable of being balanced or <u>equilibrated</u> by others.

Would it not be simpler, to proceed there (or at least more satisfactory)

1. Let h be <u>perfectly free</u> to obey any forces P Q R

2. then, there will produce in it velocities Pdt Qdt Rdt proportional to their intensities & in their direction in any instant dt. (by the laws of motion — regarding velocity as an effect of force & as its measure)

3. therefore when h is <u>free</u> $d \cdot \frac{dx}{dt} = Pdt$; &c.

& therefore multiplying these equations by δx &c.

$$((A))\ 0 = \delta x(Pdt - \frac{d^2x}{dt}) + \delta y(Qdt - \frac{d^2y}{dt}) + \delta z(Rdt - \frac{\partial^2z}{\partial t})$$

and <u>since</u> the quantities $Pdt - \frac{\partial^2 x}{\partial t}$, &c are separately zero, δx, δy, δz are absolutely arbitrary & independent — and vice versa, <u>if</u> they <u>are</u> so this one eq[uation] will be equivalent to the three separate ones.

<u>Case II.</u> But if h be not free it must be either constrained to move on some curve, or on some surface or be subjected to some resistance, or

otherwise subjected to some condition. But matter is not moved otherwise then by force — therefore whatever constrains it or subjects it to conditions is force. If a curve or a surface, or a string tying it, this <u>force</u> is called reaction — if a viscous medium, <u>resistance</u>. If a condition however abstract, (for example that it move in a tautochrone &c) still this condition, by obliging it to move out of its free course or with an irrational velocity, must resolve itself for [illegible] analysis into <u>Force</u> — only that in this case it is an <u>implicit</u> not explicit Function of the coordinates. It may therefore be considered 1st as involved in P, Q, R, or 2nd as added in the resolved forms P$'$ Q$'$ R$'$ to them if we prefer it.

In the first case, if we regard it as involved in P, Q, R, there really constrain an indeterminate function. But the equations $Pdt - \frac{d^2t}{dt} = 0$; $Q\partial t - \frac{\partial^2 y}{\partial t} = 0$ &c still subsist and <u>therefore</u> also the equation ((A)). But these are now not enough to determine x, y, z in functions of t <u>because</u> of the unknown forms of P, Q, R. But if we superadd to these equations the equation or equations (u = 0) with all their consequences ($\delta u = 0$, $du = 0$ &c) which express the <u>conditions of constraint</u>. These will then be sufficient to determine the problem. Thus our equations are $u = 0$; $(P - \frac{d^2x}{dt^2}) = 0$; $(Q - \frac{d^2y}{dt^2}) = 0$; $(R - \frac{d^2z}{dt^2}) = 0$.

u is a function on x, y, z; P, Q, R and t and P, Q, R being implicit functions of x, y, z, t, u is a function of x, y, z, t. Therefore the equation u = 0 <u>establishes</u> the existence of a relation $p\delta x + q\delta y + r\delta z = 0$ between the variations δx, δy, δz which can no loner be regarded as arbitrary. But the equation ((A)) subsists whether they be so or not & may therefore be used simultaneously with $\delta u = 0$. To eliminate one — after which the other two, being <u>really</u> arbitrary their coefficients <u>must</u> be separately zero.

In the second case if we will not regard the forces arising from the conditions of constraint as <u>involved</u> in P, Q, R, Let $\delta u = 0$ be that condition and Let P$'$, Q$'$, R$'$ be the unknown forces brought into action by that condition, by which the free action of P, Q, R is modified. then with the <u>whole</u> forces acting on h be P + P$'$ Q + Q$'$ R + R$'$ and under the influence of these the body will move <u>as a free body</u> and therefore δx, δy, δz, being any variations we have

$$0 = (P + P' - \frac{d^2x}{dt^2})\delta x + (Q + Q' - \frac{\partial^2 y}{\partial t^2})\delta y + (R + R' - \frac{\partial^2 z}{\partial t^2})\delta z$$

& this equation is independent of any particular relations between δx, δy, δz & holds good whether they subsist or not.

<u>But</u> the condition $\delta u = 0$ establishes a relation, of the form $p\delta x + q\delta y + r\delta z = 0$ where $p = (\frac{du}{dx})$; $q = (\frac{du}{dy})$ and since this is true it is so when multiplied by any <u>arbitrary</u> quantity λ when it becomes

$$p \cdot \lambda\delta x + q \cdot \lambda\delta y + r \cdot \lambda\delta z = 0.$$

Let this be added to ((B)) and it becomes

$$(P + P' - p\lambda - \frac{d^2x}{dt^2})\delta x + (Q + Q' - q\lambda - \frac{\partial^2 y}{\partial t^2})\delta y + \ldots (z) = 0$$

which is true whatever δx, δy, δz and λ are.

Now since P' Q' R' are forces acting in the directions x y z (tho' unknown) they may be compounded into one resultant S which <u>must</u> have <u>one</u> direction whose element may be represented by δs and since the single force S is resolvable into P' Q' R', we must have

$$P'\delta x + Q'\delta y + R'\delta z = S\delta s$$

so that the above equation becomes

$$(P - \frac{d^2x}{dt^2})\delta x + (Q - \frac{\partial^2 y}{\partial t^2})\delta y + (R - \frac{\partial^2 z}{\partial t^2})\delta z + S\delta s - \lambda\delta u = 0$$

and this is true <u>whatever</u> be λ

But λ being thus left arbitrary, we are at liberty to determine it by any convenient condition. Let this condition be then $S\delta s - \lambda\delta u = 0$ or $\lambda = S \cdot \frac{\delta s}{\delta u}$ & the equation reduces to ((A)) so that still this equation (when P, Q, R, are only the acting forces <u>explicitly</u> given) suffices to resolve the problem provided we take it in conjunction with the equation $p\delta x + q\delta u + r\delta z = 0$ which establishes a relation between δx δy δz.

Let us now consider the condition $\lambda = S \cdot \frac{\delta s}{\delta u}$ by which we determined λ. Since S is the resultant <u>of the forces</u> P' Q' R' its magnitude must be represented by $\sqrt{P'^2 + Q'^2 + R'^2}$ and since $S\delta s = \lambda\delta u$ or $P'\delta x + Q'\delta y + R'\delta z = \lambda\frac{du}{dx}\delta x + \lambda\frac{du}{dy}\delta y + \lambda\frac{du}{dz}\delta z$

Therefore in order that δx, δy, δz may remain arbitrary we must have $P' = \lambda \cdot \frac{du}{dx}$ $Q' = \lambda \cdot \frac{du}{dy}$ $R' = \lambda \cdot \frac{du}{dz}$ and consequently $S = \sqrt{P'^2 + Q'^2 + R'^2} = \lambda \cdot \sqrt{(\frac{du}{dx})^2 + (\frac{du}{dy})^2 + (\frac{du}{dz})^2}$ and

$$\lambda = \frac{S}{\sqrt{(\frac{du}{dx})^2 + (\frac{du}{dy})^2 + (\frac{du}{dz})^2}}; \quad P' = \frac{(\frac{du}{dx})}{\sqrt{(\frac{du}{dx})^2 + (\frac{du}{dy})^2 + (\frac{du}{dz})^2}}; \&c. ((B))$$

This is being given in terms of x, y, z; λ, P', Q', R' are all determined.

If the condition of constraint be pressure against a Surface S is the reaction &c.

<div style="text-align: right">I am dear Madam yours very truly J F W Herschel.</div>

HS/16/333

My dear Sir

Nothing can be kinder than your early communication of the translation of the Mec. Cel. I have gone through the commentary as far as the time has permitted and excellent as the notes are, I confess I am not dismayed as I rather wish to state principles clearly, and to arrive at the results by as easy methods as possible, than to enter into all the mathematical detail. I daresay you think me very bold, but I do feel inclined to proceed and to get it into the press as soon as possible. I am going to send you something on La Grange's variation of Constant quantities for though it is the line I have taken as you will see I do not think I have given a demonstration of the principle.

Y[our]s ever gratefully

M. S.

HS/16/334

Slough March 31/30

My dear Madam,

I have here so much of the latter part of your MS as I have read, and with the exception of one or two slight observations (which I have noted) I don't think it can be materially improved. perhaps a <u>little</u> explanation of the <u>object</u> of the curious analytical proof by which the arbitrary constants are so beautifully [illegible] in the integrals of the General Equations of the Elliptic motions might be desirable (vis: to facilitate the expression of the variations of the Elements) — but perhaps you have reserved this for that part in which you treat expressly of this point. I shall think it no trouble to resume the subject when retouched & interpolated however as you prefer and, indeed, shall probably find greater facility in doing so and obtain a better general view by doing so than by at once returning the whole — which however I will take can you shall have next Thursday through the kindness of our good friend.

I am happy to be able to tell you that this morning Mrs H presented me with a daughter and is as well as can be reasonably wished for.

I am dear Madam

yours very truly
J F W Herschel

HS/16/335

My dear Sir

We heartily rejoice in the agreeable intelligence you sent us, and offer our kindest congratulations on the safe arrival of the young Lady and the welfare of her blooming Mother; I trust they are both gaining strength that your new honor of being a Father may have no allay. your thinking of my affairs at such a moment is a mark of friendship truly valuable and gratifying to yours

ever sincerely
Mary Somerville

R. H. Chelsea 5th April

HS/16/336

[In pencil: 15 May 1830]

My dear Sir,

As you kindly said you would not think it a trouble to look over my MSS after I had made the alterations I intended I send it but not without some hesitation although I dare not print without knowing that it does not contain any great blunders. Do not be alarmed at seeing the whole, as such I wish you to judge of it the greater part you have already looked at, and to save your time I have marked the passages of which I am doubtful. The introduction is altogether new.

From page 49 to 133 you did not send back.

I cannot let you forget your promise of giving me your two new works, I value those I have got so highly that I look forward with real pleasure to every thing that comes from your pen. I trust Mrs Herschel and the baby are quite well offer my kindest regards to her and believe me ever

gratefully yours
M. Somerville

[Addressed to J. F. W. Herschel Esquire]

HS/16/337

Slough June 15 1830

My dear Madam,

I propose on Saturday morning to call on my way from London to deliver over to you your MS. which I have now detained so very long as to be, I fear almost beyond the reach of apology. The truth is I had hopes to have found leisure to have read more deeply on some of the subjects treated of such as the carrying the approximations to the squares of the masses — the attraction & perturbative influence of the Sun, and the theory of the rotary motion of solids, of which I never possessed more than a superficial knowledge so as to become better qualified to criticize what you have said respecting them. But the hope proved vain, so far from being able to increase my stock of knowledge on these or similar subjects I find is daily sliding from me, and the demands on my attention from less [illegible] quarters become daily more numerous and more pressing so as to take from me not only the hope, but also the wish to penetrate farther into these recesses.

Where I <u>have</u> seen my way clearly I have not spared remark and even where I have <u>thought</u> I perceived room for objection I have considered it my duty to point it out for your own judgement. Such a case arises in your 85th Page where you treat of the conditions of permanent rotation. There is one part of the theory of perturbations that seems to me to want elucidation [illegible] & you would do a service to many — me among the rest by clearing up an obscurity that hangs about it. I mean the <u>constant</u> part of the effect of perturbation, in permanently altering the elements from what they would be in an undisturbed system, or the destruction of the arc proportional to the time in the series for δv. In the theory of the moon if I remember right Plana has estimated the <u>permanent</u> effect of the Sun in altering the Lunar period & this I suppose is the analytical translation of what Newton calls the mean effect of the [ablation?] force, & I do not see <u>why</u> the same view should not be taken of planetary action.

The equations of stability $m\sqrt{a} \cdot e^2 + m'\sqrt{a'} \cdot e'^2 + \&c = C$ &c seem to me to have had their importance much overrated. It is quite clear that, <u>taken alone</u>, they prove nothing for the stability of the orbits of the small near planets. For suppose Jupiter & Mercury in which $m' : m :: 2025810 : 1067$ and $a' : a :: 5.20 : 0.39$ the equation would be

(supposing no other planets) $\frac{e'^2}{4697} + \frac{e^2}{3244000} = 0.000004954$. Now if <u>this</u> <u>alone</u> limits the values of e & e' it is clear that e' becoming $= 0$, e may attain the value $\sqrt{3244000 \times 0.000004954} = 4.009$ so that, for any thing this equation of stability might say to the contrary, the orbit of mercury might run out into an hyperbola, while that of Jupiter would presume a dignified repose as becomes his god-ships importance. — after reading this, just turn to page 305 vol 1. Book ii. Mec. Cel. 1$^{\text{st}}$ Edition & compare it with Laplace's words speaking of this equation.

But in fact, <u>is it</u> not by means of perturbative action that the orbit of [symbol]] has attained its actual ugly excentricity[sic].

Mrs H begs to be remembered to you. It is but a few days that we heard of Dr Somerville's severe loss — which has our hearty condolences.

<div align="right">yours very truly J F W Herschel.</div>

[Addressed to Mrs Somerville, Royal Military College, Chelsea]

HS/16/338

My dear Sir

I send you a method of estimating the variations in the elements of the orbits during the periods of the perturbations in longitude and distance which will supersede the integration by parts of the same quantities depending on the second powers of the excentricities[sic] and inclination. I have applied this method to the great inequalities in the mean motions of Jupiter and Saturn in the end of the M.M.S. where this may come in if you approve.

I beg you will give my love to Mrs Herschel who I trust is perfectly recovered. I hope you have also had good accounts of her brother. Believe me

<div align="right">ever sincerely yours
Mary Somerville</div>

Chelsea 23d October

HS/16/339

My dear Sir

If you will have the kindness to send the astronomical part of my MSS by Mr Richards on thursday I think I can improve it very much. I mean the part that corresponds to La Place's second book and all that follows.

yours truly

M. S.

Tuesday

HS/16/340

Saturday

My dear Sir

Our heads are no longer in danger as I have used a counter spell to keep the moon at a due distance. After so severe a season I assure you I have no wish to pay her a visit, far less to receive so cold a guest. I cannot understand by what spell I made gravitation increase with the distance, sure enough my computation was sadly careless.

I will be particularly obliged to you if you will send the part of my MSS from page 170 to the end as I have been making improvements and I think I can retouch it with advantage though it would give you infinite trouble to interpolate what I have written. You may retain the part from page 50 to 133 till it is convenient for you to look it over. I really am ashamed at the trouble I give you and cannot express how sensible I am of your kindness in devoting time to me which is so fully employed in your own careful and elegant works. With our united and best wishes to Mrs Herschel and yourself believe me

ever truly yours

M. S.

HS/16/341

[Copy] Chelsea 11 Feb [1831] [Original sent to Sir W. Fairfax Bart July 1885]

From Mrs Somerville To J. F. W. Herschel

My dear Sir,

I think it would be a great improvement to integrate the differential equations of the perturbations of the planets by the method of

indeterminate coefficients. I have applied it to the radius vector and as I have arrived at the same result with La Place I cannot see an objection. I avoid the terms having the mean anomaly as a coefficient which answers better since I determine the secular inequalities by the variation of the constant quantities. Should you approve of this plan I shall employ the same method for the perturbations depending on the other powers of the excentricities. This also saves the trouble of transforming the equation.

$$0 = \frac{d^2 r \delta r}{dr^2} + \frac{u r \delta r}{r^3} + 2 \int dR + r(\frac{dR}{dr})$$

into a similar equation in function of u (see LaPlace vol 1st pages 260, 261)

I beg my kindest wishes to Mrs Herschel who I hope is quite well. Ever my d[ea]r Sir

<div align="right">

sincerely y[ou]rs

M. Somerville

</div>

HS/16/342

My dear Sir

I have great doubts as to the integration of the equation

$$\frac{d^2 r \delta r}{dt^2} + n^2 r \delta r = 2 \int dR + r(\frac{dR}{dr})$$

and am persuaded that in such a dilemma you will forgive me for for[sic] asking your advice. The method I have followed is that of Pontecoulant by which terms of the form

$$m' D e \cdot nt \cdot \sin(nt + \epsilon - \omega)$$

are avoided altogether as you will see in page [blank] but in talking the matter over with Mr Lubbock he says Pontecoulant is wrong. Now I know that the true integral is

$$\frac{r \delta r}{a^2} = 2m' a g + \&. + m' f e \cos\{(1 + c)nt + \epsilon - \omega\}$$
$$+ m' f' e' \cos\{(1 + c')nt + \epsilon - \omega\} + \&c \& c$$

or resolving the cosines

$$\frac{r\delta r}{a^2} = 2m'ag + \&. + m'fe\cos(nt + \epsilon - \omega) + m'f'e'\cos(nt + \epsilon - \omega')$$
$$- m'fecnt \cdot \sin(nt + \epsilon - \omega) - m'f'e'c'nt \cdot \sin(nt + \epsilon - \omega') + \&c\&c.$$

which is the same with La Place's but then I do not know how I am to get rid of c and c' so that the terms containing the arc nt may vanish. This point is so difficult that I trust it will be some excuse for intruding on your time.

I congratulate you on the appearance of one of the most perfect works that our language can boast of. Sir James Mackintosh begged of me to make him acquainted with you that he might express his profound admiration of your book, he says nothing has been written like it since Bacon's nouveau anganum. Mr Hallam the historian expressed the same opinion. — We lament seeing so little of you and wish Mrs Herschel and you would spend a day with us the first time you come to town. I trust the baby is well with every kind regard to Mrs H and you believe me

very truly y[ou]rs
M. Somerville

R. H. Chelsea
3^d March

[Postscript from William Somerville: My dear Sir. I confess that I have [illegible] Mrs S's scruples to intrude upon you, & to stop the press in the hope that you will accede to her solicitation. To save you as much trouble as I can I send envelopes to return her sheets addressed to her, under cover to [illegible] &c.

yours very faithfully
W Somerville

The address to her is enough on the inner cover.]

[Addressed to J. F. W. Herschel Esq]

HS/16/343

Slough March 8 1831

Dear Madam,

If you have any doubt about Pontecoulant's method of indeterminate coefficients, (I have not his book), your better way will be to

abandon it altogether and throw yourself on the broad principles of Laplace as laid down in N^o43 of the 2nd book of the Mec. Cel. , or as he has explained it rather more clearly I think, than in the condensed and general form in which it is stated in the Mec. Cel. in the Mem Acad. Sci. 1772 P373 in a very beautiful memoir, which I would recommend you to look at.

The outline of the principle is this. — Direct approximation leads to an integral consisting of terms of 2 kinds, periodical and algebraic — the former of the form sin or $\cos(A + Bt)$ The latter of t, t^2 &c But never any term of the form sin, $\cos(A + Bt + Ct^2)$ (If such a term as the latter could occur, the method would be inapplicable, but by tracing the approximation step by step we shall easily see that no such term can arise. This ought to be very plainly stated in illustrating the principles to elementary readers).

By thus having one or two steps of approx[imatio]n we discover the General form of the integral of $\frac{d^i y}{dt^i} + P + \alpha Q = 0$ to be[1]

$$y = \&c + (A + Bt + Ct^2 + \&c) \cdot \sin[\cos](m + NT) + \&c$$

Now therefore let such a general series be substituted for y and Since t only enters in the periodical terms of the 1st degree, no power of t can be produced by differentiation but what arose from parts without the sin & cos nor can any of the terms out of the [illegible] sin, cos be ever introduced into them by such an operation. Consequently, in this substitution we may (for a moment) regard the t out of and the t in the sines & cosines as independent and denote them by different letters such as v and t and then we have

$$y = \sum (A + Bv + Cv^2 + \&c) \times \sin[\cos](m + nt)$$

[Where $\frac{dt}{dt} = \frac{dv}{dt}$].

2) Now this substitution being made as above in $\frac{\partial^i y}{\partial t^i} + P + \alpha Q = 0$ an equation of the form $0 = k + k'v + k''v^2 + \&c$ must evidently arise, where $k, k', \&c$ are terms composed of $\sin[\cos](m + NT)\&c$ and it is evident that if we can determine the assumed series so as to make $k = 0, k' = 0, k'' = 0$ &c all will be right and v will go out.

Instead of putting $y = \sum (A + Bt + Ct^2...) \cdot \sin[\cos](m + Nt)$ we may write it as Laplace does $y = X + tY + t^2 Z + \&c$ where X, Y, Z are periodic terms of the form sin or $\cos(m + NT)$ or series of such terms, and the same reasoning still subsists — when substituted the result will still be an equation such as $k + k'v + k''v^2 + \&c = 0$ and we may

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1 We here use sin[cos] to mean that the function can be the sine or cosine. Herschel indicated this by writing sin and cos one above the other in the equation.

then suppose $y = X + vY + v^2Z + \&c$ provided after the differentiations we make $\partial v = \partial t$. Now this comes to the same as supposing $v = t + const$ or $(t - \theta)$ and thus <u>if</u> $y = X + tY + t^2Z + \&c$
satisfy the eqn
<u>then</u> $y = X + (t - \theta)Y + (t - \theta)^2Z + \&c$ will satisfy it also

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The next step is this. θ is an arbitrary constant. But by supposition $y = X + tY + t^2Z + \&c$ is the complete integral — <u>therefore</u> the zero arbitrary constant θ is only apparently so — <u>therefore</u> it must be a function of the other arbitraries c, c', c'' &c contained in y — <u>Therefore</u>, reciprocally, <u>if</u> $X + (t - \theta)Y + (t - \theta)^2Z + \&c$ be capable of being regarded as a transformation of $X + tY + t'Z + \&c$, <u>then</u> $c, c',$ &c must be certain functions of θ, and X, Y, Z being functions of $c, c',$ &c must also be functions of θ — such functions may always found, or supposed.

It is therefore [illegible] to assume for $c, c',$ &c such functions of θ as shall make $X + Y(t - \theta) + Z(t - \theta)^2 + \&c$ a legitimate transformation of $X + Yt + Zt^2 + \&c$.

3rd step Now if this transformation be generally possible as an algebraic truth it will be still true (being independent of θ's particular value) when $\theta = t$ & in that case we have $y = X$; observing that in this expression X which is a function of $c, c',$ &c and thereby a function of θ becomes now a function of t of a quite different nature from what it was before by writing t for θ.

If then the nature of X regarded as a function of θ, as well as of periodical functions of t can be found — such as $X = \phi(t, \theta)$ then will the [illegible] value of y be $y = \phi(t, t)$.

The problem is reduced to this
XYZ&c & are functions of $c\ c'\ c''$ &c of a given form
$c\ c'\ c''$ & are functions of θ of an unknown form (to be found by the condition that

$$X + tY + t^2Z\&c = X + (t - \theta)Y + (t - \theta)^2Z + \&c$$

is an equation to be verified independent of particular values of t & θ. ~~Req[d] the forms of X, c, c', c'' &c in θ, t~~
now it will be observed that this equation being to be made identical in θ, the 1st member does not ~~explicitly~~ contain it, and therefore the 2^d when developed in θ may have all the differential coefficients $= 0$ to that we see developing

$$X + Yt + Zt^2 + \&c = X + Yt + Zt^2 + \&c +$$

$$\theta\{\frac{dX}{d\theta} - Y\} + \theta^2\{\frac{d^2X}{1 \cdot 2 \cdot d\theta^2} - \frac{dY}{1 \cdot dt} + Z\} + \&c$$

Comparing Like terms and destroying the powers of θ we see $Y = \frac{dX}{d\theta}$; whence $\frac{\partial Y}{\partial t} = \frac{d^2X}{d\theta^2}$ so that $2Z = \frac{dY}{d\theta}$, &c which are the same equations Laplace gets by a somewhat different consideration.

Step 5. Thus Y, Z, &c are given in functions of θ when X is once so expressed, and its differential coefficients. These diff[erentia]l co-efficients however it will be observed will involve terms arising from c, c′, c″, &c as follows

$$\frac{dX}{d\theta} = \frac{dX}{dc} \cdot \frac{dc}{d\theta} + \frac{dX}{dc'} \cdot \frac{dc'}{d\theta} + \&c$$

$$\frac{dY}{d\theta} = \frac{dY}{dc} \cdot \frac{dc}{d\theta} + \frac{dY}{dc'} \cdot \frac{dc'}{d\theta} + \&c$$

Now if any of the of the c enter into a periodic term as a constant as for instance in the term cos or $\sin(ct + const)$ and if X, Y, &c either of them contain such a term, there will arise a term in $\frac{dX}{d\theta}$ of the form $t \times \sin$ or $\cos(ct + const) \times \frac{dc}{d\theta}$ containing the arc t and therefore the general form of $\frac{dX}{d\theta}$ will be

$$\frac{dX}{d\theta} = X' + T \cdot X''$$

and so of the rest.

So the equations determining the identity in question take the form

$$Y = X' + \theta \cdot X''$$

$$2Z = Y' + \theta \cdot Y'' + X''$$

(for the way in which θ gets in here instead of t see Laplace. There is no difficulty about it).

Step 6. In these X′, X″, Y′, Y″, &c are composed entirely of periodic terms in t and linear terms of the form $\frac{dc}{d\theta}, \frac{dc'}{d\theta'}, \&c$

Now the object is 1st to get the values of these & thence by substitution in X, Y, &c those of the latter in terms of θ. To this end, we observe, 1st that t and θ are independent 2nd that each equation is linear in $\frac{dc}{d\theta}$, &c & θ so that they are in fact a system of simultaneous

linear differential equations in c, c′, c″, &c by whose integration (regarding t as arbitrary & independent and treating c, c′, &c and θ as the variables. These may be had moreover since t is arbitrary any of these equations may be differentiated with regard to t alone, & thus equations of greater simplicity obtained.

I think this is about the [illegible] view of Laplace's method, but it is delicate & should be explained in full detail. It is extraordinary to me how I have forgot these things. I was once very familiar with this part of the Mec. Cel. — and yet I always found some thing catching in the reasoning & I know by experience how easy it is to make a slip in it.

I am much flattered by your & Sir J Macktintosh's approbation of my book — one word of such praise is worth a whole volume of newspaper & magazine puffering with which it has been treated & which really had made me almost feel that I must have written something very foolish. But you reassure me. With comp[limen]ts to Dr S in which Mrs H joins, I am, dear Madam,

J F W Herschel

[Addressed to Mrs Somerville, Chelsea Hospital near London]

HS/16/344

My dear Sir

I am tempted by your constant kindness to me to submit to you a few preliminary observations which are to be prefixed to my book now ready for publication, and shall be most grateful if you will look it over and mark on the blank pages any thing that strikes you without which I should be unwilling to let it appear before the public.

I trust Mrs Herschel and your little girl are quite well. we unite in best wishes to her and to you, and believe me

my dear Sir very truly yours
M. Somerville

R.H. Chelsea 28th May

[Addressed J. W. F. Herschel Esquire]

HS/16/345

My dear Madam

I return your Proofs with whose perusal I have been I assure you highly gratified, with such [illegible] as have received. The only remark of much consequence is that opposite to page xii when, in the hurry of composition you have taken the circle for a limiting case instead of the parabola — Perhaps too you would see no objection against modifying the expressions in p. lxiii and lxiv something according to what I have marked.

The star I allude to as having entered on its 2^d revolution is γ Corona, one of the most difficult of all the double stars to measure from its extreme closeness

The measures of it Stand thus

1.	1781 . 69	Position 30°41′ my Father
2.	1802 . 69	359 40 (by two measures agreeing perfectly) &°
3.	1823 . 17	25 57 — South and myself
4.	1830 . 30	44 25 my own measure
5.	1831 . 31	51 41 &°

The two last measures appear decisive, but that I might make sure of my own exactness (in so very difficult a case) I requested Mr Dawes of Ormskirk who has an excellent telescope and knows how to uses it excellently, to measure the star which he did without knowledge of my results and his measure comes out as follows

$$1831 . 34 — 50°46′$$

The apparent priority of date arises from <u>mean</u> epochs having been taken — the best observations in fact were nearly simultaneous with Mr. Dawes'.

The measure N° 2 should I apprehend be diminished by 180° — a mistake in this point is extremely easy to commit in η whose two stars differ very little in magnitude.

I suppose it cannot now be long before the book appears. Pray let me request a copy if you have any [illegible] at your disposal as early as possible.

You will be happy to heat that Mrs H on Sunday presented me with a fine girl & is doing perfectly well.

> With Compts for Dr S
> am dear Madam

Yours very truly
J F W Herschel

[Addressed Mrs Somerville]

CALCULUS TEXTS PUBLISHED IN GREAT BRITAIN, 1820–1840, AND THEIR AUTHORS

E.1 BOOKS

Books marked with an asterisk (*) were contained in Mary Somerville's collection of books donated to Girton by her daughters after her death.

Year	Author	Title
1820	Peacock, George	A collection of examples of the application of the differential and integral calculus*
1823	Hawkes, Samuel	A sketch of the principles of the Differential Calculus, with an appendix
1824	Browne, Arthur	A short view of the first principles of the differential calculus
1825	Coddington, Henry	An introduction to the differential calculus on algebraical principles
1825	Lardner, Dionysius	An elementary treatise on the Differential and Integral Calculus
1826	Jephson, Thomas	The fluxional calculus: an elementary treatise, designed for the students of the universities, and for those who desire to be acquainted with the principles of analysis. Volume 1
1827	Myers, Charles John	An Elementary Treatise on the Differential Calculus
1828	Blakelock, Ralph	An elementary treatise on the Differential and Integral Calculus, by J. L. Boucharlat. Translated from the French.
1828	Higman, John Philips	A syllabus of the differential and integral calculus. Part II. containing the remainder of the differential calculus

Year	Author	Title
1828	Hind, John	The principles of the differential calculus. Designed for the use of students in the University
1829	Powell, Baden	A short treatise on the principles of the differential and integral calculus. Designed for the use of students in the university.
1830	Jephson, Thomas	The fluxional calculus: an elementary treatise, designed for the students of the universities, and for those who desire to be acquainted with the principles of analysis. Volume 2
1830	Powell, Baden	An elementary treatise on the geometry of curves and curved surfaces, investigated by the application of the differential and integral calculus. Designed for the use of students in the university.
1831	Hymers, John	A treatise on the Integral Calculus: part 1, containing the integration of explicit functions of one variable; together with the theory of definite integrals and of elliptic functions.
1831	Jarrett, Thomas	An essay on algebraic development, containing the principal expansions in common algebra, in the differential and integral calculus, and in the calculus of finite differences; the general term being in each case immediately obtained by means of a new and comprehensive notation.
1831	Young, John Radford	The elements of the integral calculus; with its applications to geometry and to the summation of infinite series. Intended for the use of mathematical students in schools and universities

Year	Author	Title
1831	Young, John Radford	Elements of the Differential Calculus comprehending the general theory of curve surfaces and of curves of double curvature
1832	De Morgan, Augustus	Elementary illustrations of the differential and integral calculus
1832	Earnshaw, Samuel	On the notation of the Differential Calculus
1832	Hind, John	A digested series of examples in the applications of the principles of the differential calculus. Designed for the use of students in the University.
1833	Miller, William Hallows	An Elementary Treatise on the Differential Calculus
1833	Young, John Radford	The elements of the differential calculus; comprehending the general theory of curve surfaces, and of curves of double curvature. Intended for the use of mathematical students in schools and universities.
1834	Hall, Thomas Grainger	An elementary treatise on the Differential and Integral Calculus
1835	Anon	A collection of examples on the integral calculus, in which every operation of each example is completely effected. By a member of the university.
1836	Anon	First lessons in differential and integral calculus
1836	De Morgan, Augustus	The differential and integral calculus*
1836	Ritchie, William	Principles of the Differential and Integral Calculus: familiarly illustrated , and applied to a variety of useful purposes: designed for the instruction of youth.

Year	Author	Title
1837	Forbes, John	The theory of differential and integral calculus, derived synthetically from an original principle
1838	Baily, John & Lund, Thomas	A treatise on the differential calculus. Designed for the use of students in the university.
1838	Ottley, William Campbell	A treatise on the differential calculus, with a collection of examples.
1838	Tattershall, Thomas	An elementary treatise on the differential and integral calculus
1838	Whewell, William	The Doctrine of Limits, with its applications; namely, conic sections, the first three sections of Newton, and the differential calculus.
1839	Hymers, John	A treatise on differential equations, and on the calculus of finite differences
1839	Thomson, James	An introduction to the differential and integral calculus. With an appendix illustrative of the theory of curves

Table 5: Texts on the calculus published in Britain between 1820 and 1840, not including 2nd editions. Sourced from the online catalogues of the Bodleian Library, Oxford, the University Library, Cambridge, and the British Library, London on 29/02/2021.

E.2   AUTHORS

Author	Wrangler	Institutional Affiliation	FRS	FRAS
Baily, John	2nd 1828	Fellow, St John's, Cambridge		
Blakelock, Ralph	13th 1825	Fellow, Catharine Hall, Cambridge		
Browne, Arthur	6th 1819	Fellow, St John's, Cambridge		

Author	Wrangler	Institutional Affiliation	FRS	FRAS
De Morgan, Augustus	4th 1827	Professor of Mathematics, University of London		1828
Earnshaw, Samuel	Senior, 1831	Fellow & coach, St John's, Cambridge		
Forbes, John		Minister of St Paul's Glasgow		
Hall, Thomas Grainger	5th 1824	Professor of Mathematics, Kings College London & Fellow of Magdalene College, Cambridge		
Hawkes, Samuel	12th 1818	Fellow, Trinity College, Cambridge		
Higman, John Philips	3rd 1816	Fellow, Trinity College, Cambridge	1819	1821
Hind, John	2nd 1818	Fellow, Sidney Sussex, Cambridge		
Hymers, John	2nd 1826	Fellow, St Johns, Cambridge	1838	
Jarrett, Thomas	34th 1827	Fellow, Catharine Hall & Professor of Arabic, Cambridge		
Jephson, Thomas	4th 1806	Fellow, St John's, Cambridge		
Lardner, Dionysius		Professor of Natural Philosophy and Astronomy, University of London	1828	
Lund, Thomas	4th 1828	Fellow, St John's, Cambridge		
Miller, William Hallows	5th 1826	Fellow, St John's, Cambridge and Professor of Mineralogy, Cambridge	1838	
Myers, Charles John	5th 1823	Fellow, Trinity College, Cambridge		

Author	Wrangler	Institutional Affiliation	FRS	FRAS
Ottley, William Campbell	16th 1832	Fellow, Gonville and Caius, Cambridge		
Peacock, George	2nd 1813	Fellow, Trinity College, Cambridge	1817	1820
Powell, Baden		Savilian Chair of Geometry & Fellow, Oriel College, Oxford	1824	1838
Ritchie, William		Professor of Natural Philosophy, Royal Institution of Great Britain and Professor of Natural Philosophy and Astronomy, University of London	1828	
Tattershall, Thomas	7th 1816	Fellow of Queens' College, Cambridge		
Thomson, James		Professor of Mathematics in the University of Glasgow	1821	
Whewell, William	2nd 1816	Fellow, Trinity College, Cambridge	1819	1821
Young, John Radford		Professor of Mathematics in Belfast College		

Table 6: Authors of texts on the calculus published in Britain between 1820 and 1840.

F

SOMERVILLE'S DERIVATION OF THE DIFFERENTIAL IN *THEORY OF DIFFERENCES*

[This is a transcription of *Theory of Differences*, MS Dep. d. 207, MSAU2–7, pp. 2–4. The authors notation has been adhered to as far as typesetting would allow: note that Fx denotes the function F evaluated at x, usually denoted $F(x)$.]

The object of the Differential Calculus, is to determine the change that takes place in a function, in consequence of a gradual change in the quantities it contains.

Let Fx be a function of a variable quantity x, which becomes $F(x + h)$ when x is $x + h$. Then the expression $F(x + h) - Fx$ is the change produced in the function in consequence of the increase of x; or it is the difference of the function corresponding to the difference of the variable quantity; that difference may be represented by Δ, a function of x and h that vanishes when h is zero, hence

$$F(x + h) - Fx = \Delta$$

Since Δ vanishes when the increment is zero, its nature is so far known, but there are an infinite number of functions of x and h possessing that property, and it is impossible to demonstrate which of these Δ may be, therefore the development of that difference must be accomplished by the arbitrary use of some function of x and h which vanishes when h is zero. But a function of x and h may always be found such, that,

$$\Delta : h :: \varphi(x + h) : 1$$

whence $\Delta = h\varphi(x + h)$ and thus Δ is determined so as to vanish with h, consequently

$$F(x + h) - Fx = h\varphi(x + h)$$

Now $\varphi(x + h) = \frac{F(x+h) - Fx}{h}$ and when $h = 0$, $\varphi(x) = \frac{0}{0}$ an indeterminate function of x which does not vanish with h. φx is therefore in all respects similar to Fx. Consequently when x becomes $x + h$, φx is changed to $\varphi(x + h)$ and $\varphi(x + h) - \varphi x$ is the difference produced in the function φx by a change in the variable x; and as this difference also vanishes with the increment, it is possible to find a quantity $\varphi'(x + h)$ so that $\varphi(x + h) - \varphi x = h\varphi'(x + h)$ in the same manner as before.

Again it may be shown that $\varphi'x$ is an indeterminate function of x alone, and since this process may be continued indefinitely a series of equations may be found as follows,

$$F(x+h) = Fx + h\varphi(x+h)$$
$$\varphi(x+h) = \varphi x + h\varphi'(x+h)$$
$$\varphi'(x+h) = \varphi'x + h\varphi''(x+h)$$
$$\varphi''(x+h) = \varphi''x + h\varphi''(x+h)$$
$$\&c \qquad \&c$$

If these values of $\varphi(x+h)$, $\varphi'(x+h)$, &c be substituted successively in $F(x+h) = Fx + h\varphi(x+h)$ the result will be,

$$F(x+h) = Fx + \varphi x \cdot h + \varphi'x \cdot h^2 + \varphi''[x] \cdot h^3 + \&c \qquad \text{(A)}$$

From the manner in which this series has been obtained it is arbitrary, for it might have proceeded according to ~~the~~ any function of h whatever.

The whole and positive powers of h are chosen on account of their being the most simple function of that quantity, but if the assumption be erroneous, the error will be manifest by some absurdity arising in the determination of the quantities φx, $\varphi'x$, etc which are named coefficients.

In order to determine φx the first coefficient, let the series (A) be put under the form

$$F(x+h) - Fx = h\{\varphi x + h(\varphi'x + h\varphi''x + \&c)\}$$

which expresses the whole difference of the function corresponding to the change in the variable quantity, and is independent of the value of h which is arbitrary, and may be of any magnitude whatsoever. Consequently h may be taken so small that φx shall be greater than $h(\varphi'x + h\varphi''x + \&c)$ hence $\varphi x \cdot h$ will be greater than $h^2(\varphi'x + h\varphi''x + \&c)$ and therefore in the expression

$$F(x+h) - Fx = h\{\varphi x + h(\varphi'x + \varphi''xh + \&c)\}$$

h may be taken so small that the first term of the difference shall exceed the sum of all the remaining terms of the series, and the less h is, the less will be the error in taking the first term of the difference in place of the whole difference.

The quantity $\varphi x \cdot h$ being only a part of the whole difference is called the Differential and it is usual to denote that circumstance by writing $d \cdot Fx$ in place of $F(x+h) - Fx$ which is the whole difference.

In the same manner h, which is the difference between $x + h$ and h [sic], is represented by dx when it is indefinitely small. Thus the expression

$$F(x + h) - Fx = \varphi x \cdot h + h(\varphi'xh + \varphi''x \cdot h^2 + \&c)$$

becomes $d \cdot Fx = \varphi x \cdot dx$ when the first term of the difference is taken in place of the whole difference.

$d \cdot Fx = \varphi x \cdot dx$ is called the Differential of Fx, and the coefficient φx which is multiplied by the first power of the increment is named the First Differential Coefficient, and may be found by dividing the differential of the function by the Increment thus $\varphi x = \frac{dFx}{dx}$. Hence the first differential coefficient is an indeterminate function of x alone, as has already appeared. Thus the first coefficient of the series A is determined in the case of h being indefinitely small.

If $\frac{dFx}{dx}$ be put for φx in the differential of Fx it becomes $dFx = \frac{dFx}{dx} \cdot dx$.

From this investigation the following rule for finding the differential of a function may be derived.

Rule 1

Substitute $x + dx$ in place of x in the given function, develope[sic] the result according to the whole and positive powers of dx, and having subtracted the given function from the developement, that term which is multiplied by the first power of the increment is the Differential required.

A METHOD OF DEVELOPING A FUNCTION OF A VARIABLE QUANTITY, ACCORDING TO THE WHOLE AND POSITIVE POWERS OF THE INCREMENT

[This is a transcription of a notebook entry by Somerville found in MS Dep. C. 352, MSSW–5. The authors notation has been adhered to as far as typesetting would allow: note that Fx denotes the function F evaluated at x, usually denoted $F(x)$.]

Let Fx be a function of x which becomes $F(x+h)$ when x changes to $x+h$. The expression $F(x+h) - Fx$ is the difference of the function corresponding to the difference of the variable quantity, and may be represented by Δ, a function of x and h which vanishes when $h = 0$, so that $F(x+h) - Fx = \Delta$.

Since Δ depends on the increment or on some power of it, a quantity which is a function of x and h may be found such, that, $\Delta : h^n ::$ $\phi(x+h) : 1$ or $\frac{\Delta}{h^n} = \phi(x+h)$. When $h = 0$, it is evident that $\phi x = \frac{0}{0}$ is an indeterminate and finite function of x which does not vanish when $h = 0$. This proves that none of the powers of h which $\phi(x+h)$ contained ~~could have been~~ can be infinite when h ~~was~~ is made zero. It appears also that n must be a positive number because if it were negative the equation $\Delta = h^n \phi(x+h)$ would then become $\Delta = \frac{\phi(x+h)}{h^n}$ and when $h = 0$ it would be $0 = \frac{\phi x}{0}$ or $0 = \infty$ which is impossible, therefore n is positive and $h^n \phi(x+h)$ vanishes when $h = 0$, consequently the difference of the function is justly represented by that quantity so that, $F(x+h) - Fx = h^n \phi(x+h)$.

In order to determine n, let $h = i - x$, i being constant; then

$$Fi - Fx = (i - x)^n \phi i.$$

Now let x become $x + h$ then

$$Fi - F(x+h) = (i - x - h)^n \phi i$$

but subtracting

$$F(x+h) - Fx = (i - x)^n \phi i - (i - x - h)^n \phi i;$$

now by the binomial

$$(i - x - h)^n = (i - x)^n - n(i - x)^{n-1}h+$$
$$\frac{n(n-1)}{2}(i - x)^{n-2}h^2 - \&c$$

hence

$$F(x + h) - Fx = (i - x)^n \phi i-$$
$$\phi i\{(i - x)^n - n(i - x)^{n-1}h + \frac{n(n-1)}{2}(i - x)^{n-2}h^2 - \&c\}$$

or

$$F(x + h) - Fx = \phi i\{n(i - x)^{n-1}h - \frac{n(n-1)}{2}(i - x)^{n-2}h^2 + \&c\}$$

or since $i - x = h$,

$$F(x + h) - Fx = \phi(x + h)h^n\{n - \frac{n(n-1)}{2} + \frac{n(n-1)(n-2)}{2 \cdot 3} - \&c\}$$

consequently

$$1 = n - \frac{n(n-1)}{2} + \frac{n(n-1)(n-2)}{2 \cdot 3} - \&c$$

It is evident that the conditions of this equation will be fulfilled by making $n = 1$, for the general term of the series is

$$\frac{n(n-1)(n-2)...(n-(n-1))}{1 \cdot 2 \cdot 3...n}$$

which vanishes when $n = 1$ and the equation becomes identical or $1 = 1$ hence $F(x + h) - Fx = h\phi(x + h)$.

Since $\phi(x + h)$ is a function of x and h in all respects similar to $F(x + h)$, the same reasoning is applicable to it, hence

$$\phi(x + h) - \phi x = h\phi'(x + h) \text{ and consequently}$$

$$\phi'(x + h) - \phi x = h\phi''(x + h) \text{ Indefinitely.}$$

By the successive substitution of the values of $\phi(x + h)$, $\phi'(x + h)$, &c in $F(x + h) - Fx = h\phi(x + h)$ the following series ascending according to the whole and positive powers of h will be found.

$$F(x + h) = Fx + \phi x \cdot h + \phi'x \cdot h^2 + \phi''x \cdot h^3 + \&c$$

At first I thought I had proved this Theorem but upon further consideration it appears, that in the equation

$$1 = n - \frac{n(n-1)}{2} + \frac{n(n-1)(n-2)}{2 \cdot 3} - \&c$$

a value has been <u>assumed</u> for n among an indefinite number that might equally have satisfied it, consequently it is not a demonstration, and indeed no demonstration has yet been give of this Theorem, for La Grange and all the other mathematicians who have written on the subject have virtually assumed that the series would ascend by the whole and positive powers of the Increment in place of proving it.

It may be even doubted whether it ever can be demonstrated and perhaps the best way is to make the assumption of the easiest law such as the whole and positive powers of the Increment and if it be wrong the error will become manifest by some absurdity arising in he determination of the coefficients. The coefficients may be obtained very simply from the equation $Fi = Fx + (i-x)^n \phi i$ for if its successive differentials be taken they will be

$$Fi = Fx + (i-x)^n \phi i$$
$$0 = dFx + (i-x)^n d(\phi i) - n(i-x)^{n-1}\phi i \cdot dx$$
$$0 = d^2 Fx + (i-x)^n d^2(\phi i) - 2n(i-x)^{n-1}d(\phi i)dx +$$
$$n(n-1)(i-x)^{n-2}\phi i \cdot dx$$
$$\&c = \&c \ldots$$

and if the value of $d(\phi i)$ be found from the last of these equations and substituted in the the first, the latter will only contain $d^2(\phi i)$ and ϕi and by means of it ϕi may be eliminated from $Fi = Fx + (i-x)^n \phi i$ and the result will be

$$Fi = Fx + \frac{2}{n+1} \cdot \frac{dFx}{dx}(i-x) + \frac{d^2 Fx}{n(n+1)dx^2}(i-x)^2 +$$
$$\frac{d^2(\phi i)}{n(n+1)dx^2}(i-x)^{n+2}$$

but as this process [can] be continued indefinitely,

$$Fi = Fx + \frac{2}{n+1} \cdot \frac{dFx}{dx}(i-x) + \frac{d^2 Fx}{n(n+1)dx^2}(i-x)^2$$
$$+ \frac{d^3 Fx}{n(n+1)(n+2)dx^3}(i-x)^3 + \&c$$

According to the ordinary notation h, or $i-x$ is the same with dx therefore,

$$F(x+dx) = Fx + \frac{2}{n+1}\frac{dFx}{dx}dx + \frac{d^2 Fx}{n(n+1)dx^2}dx^2 +$$
$$\frac{d^3 Fx}{n(n+1)(n+2)dx^3}dx^3 + \&c$$

Thus it appears that the development of the function $F(x + dx)$ proceeds according to the whole and positive powers of the Increment which is therefore independent of n and consequently in the ratio $\Delta : h^n :: \phi(x + h) : 1$, n must be $= 1$, hence

$$F(x + dx) = Fx + \frac{dFx}{dx}dx + \frac{d^2Fx}{2dx^2}dx^2 + \frac{d^3Fx}{2 \cdot 3 \cdot dx^3}dx^3 + \&c$$

the series obtained by Taylor.

{n is here assumed as much as in the 1st case}

MS 1822

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Items from the Herschel Papers held at the Royal Society of London are referenced using the volume and page number, eg. HS/16/343.

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