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The Maxwellian

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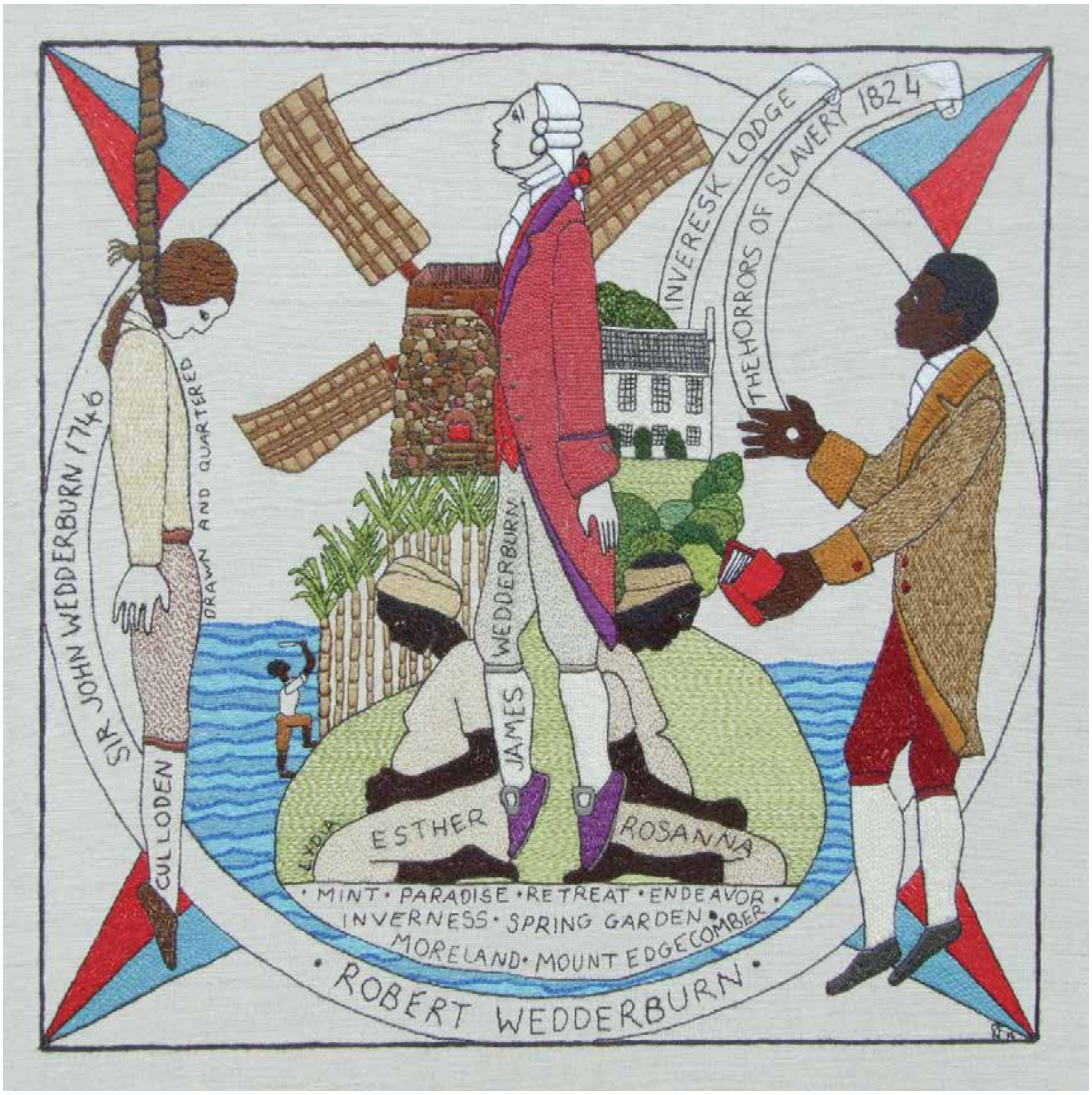

SUGAR, RUM, SLAVERY, AND MAXWELL'S AUNT ISABELLA

THE 1931 MAXWELL CENTENARY

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Front cover: JM03: 'The Wedderburns', stitched by Kate Fielding, one of the panels of the Scottish Diaspora Tapestry, © Prestoungrange Arts Festival. The panel is also shown on page 11.

Page 9: JM02: 'Scots and Plantations', stitched by Sir Geoff Palmer, one of the panels of the Scottish Diaspora Tapestry, © Prestoungrange Arts Festival.

Back cover: 'Thermodynamic surface', Figure 26d from Maxwell's *Theory of Heat*, Longmans, Green & Co., 1871.

EDITORIAL TEAM

Dr Chris Pritchard

Dr Catherine Dunn
Dr Howie Firth
Professor Peter Grant
Professor Martin Hendry

EDITORIAL

Chris Pritchard

Welcome to the fourth issue of *The Maxwellian*, a twice-yearly journal with a focus on the life and scientific legacy of the Scottish physicist, James Clerk Maxwell.

This issue begins with a review of the centenary celebrations in 1931 of Maxwell's birth. It's amazing to read in Grace Exley's article the level of respect the scientific community had for Maxwell at the time and the belief that he was undervalued in his own lifetime. With the exception of Einstein, whom we suspect was incredibly disappointed not to be able to attend, everybody but everybody was there in Cambridge: Niels Bohr, J. J Thomson, James Jeans, Max Planck, Oliver Lodge and Joseph Lamour included. It must have been a splendid occasion.

Catherine Booth takes a look at Alexander Muirhead's contribution to telegraphy. This 'stickler for precise measurements' made his mark with his 'delicate coherer' which helped clean up the sounds transmitted.

For a view of the wider context of Maxwell's measurement of electrical resistance, we are indebted to Paul Quincey. Here we learn of the adoption of the ohm, its 'definition being chosen before it could be realised accurately enough in practice'.

Also included here is a disturbing story of the involvement of one powerful Scottish family, the Wedderburns, in the production of sugar and rum in Jamaica in the eighteenth century. As you will have guessed, it's a story of chattel slavery, profit gained from imposed misery. What interests us here is that the Wedderburns formed a branch of Maxwell's father's family tree and the house in which Maxwell stayed while he attended the Edinburgh Academy was a Wedderburn house. Incidentally, the second part of this article on, 'Sugar rum and slavery', will feature the career of Andrew Wedderburn Colvile, Maxwell's Uncle Andrew, and attempts by him and others to subvert abolition and ameliorate its effects on their businesses. It will appear in Issue 5 in March 2027.

SAVING PARTON KIRK, BURIAL PLACE OF JAMES CLERK MAXWELL

Please share in our passion for James Clerk Maxwell and Parton Kirk.

Parton Kirk, burial place of the world-famous physicist James Clerk Maxwell is being sold by the Church of Scotland. Parton Community Council, has been offered the exclusive right to purchase the Kirk with the idea of developing a James Clerk Maxwell Science and Community Centre to celebrate the life and work of this great mind, a scientist who laid the foundations of our modern society, yet remains relatively unknown outside the world of science and engineering.

We have until 1st November 2026 to raise the money necessary to secure the building and take the next step towards realising the vision. We need to raise a minimum of £70,000 to secure the building for the community while we develop our plans. This figure is made up as follows: £50,000 Purchase Price, plus £20,000 Immediate costs to insure and secure the building in a wind and watertight condition while we move to the next phase.

To help Parton secure the Kirk for our community, and to celebrate the life and achievements of this giant of science, please donate via JustGiving: www.justgiving.com/crowdfunding/savepartonkirk?utm_medium=CF&utm_source=CL

Thank you!

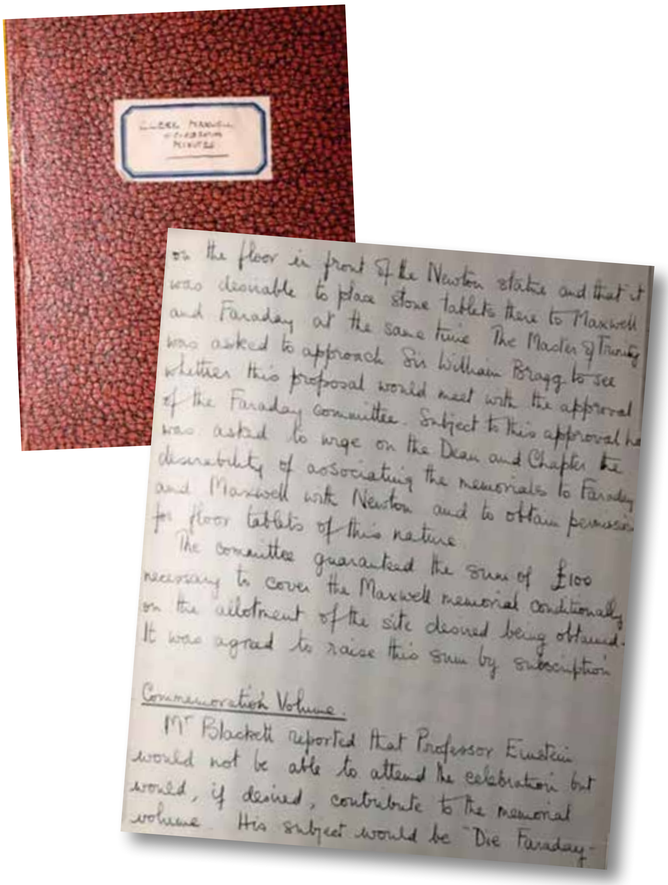
Paul Hodson, on behalf of Parton Community
Email: partoncc@gmail.com

THE 1931 MAXWELL CENTENARY CELEBRATIONS

Grace Exley

The years 1927 to 1931 were overflowing with scientific anniversaries. 1929 saw the centenaries of the deaths of Alessandro Volta, Humphry Davy and Thomas Young; the Society of Chemical Industry celebrated its fiftieth anniversary in 1931, and the bicentenary of the death of Isaac Newton took place in 1927.

So numerous were these commemorations that both Bragg and Rutherford were required almost to become part-time party planners, most notably in 1931. Marking the centenaries of Michael Faraday's discovery of electromagnetic induction, the birth of James Clerk Maxwell and the founding of the British Association for the Advancement of Science, the events of 1931 attracted the largest celebrations. They took place on the eve of 1932, the 'annus mirabilis' of nuclear physics, which would see the discovery of the neutron by James Chadwick, that of the positron by Carl Anderson, and Cockcroft and Walton 'splitting the atom'. The Faraday and BA centenary celebrations were held in London and were on a very much larger scale than the Cambridge events, which commemorated the life of James Clerk Maxwell.



on the floor in front of the Newton statue and that it was desirable to place stone tablets there to Maxwell and Faraday at the same time. The Master of Trinity was asked to approach Sir William Bragg to see whether this proposal would meet with the approval of the Faraday Committee. Subject to this approval he was asked to urge on the Dean and Chapter the desirability of associating the memorials to Faraday and Maxwell with Newton and to obtain permission for floor tablets of this nature.

The committee guaranteed the sum of £100 necessary to cover the Maxwell memorial conditionally on the allotment of the site desired being obtained. It was agreed to raise this sum by subscription.

Commemoration Volume.

Mr Blackett reported that Professor Einstein would not be able to attend the celebration but would, if desired, contribute to the memorial volume. His subject would be "Die Faraday-

Fig. 1: Minute Book of the Maxwell Centenary Celebration Committee and the page of the minutes recording Einstein's inability to attend the celebrations with his offer to contribute to the memorial volume.

Recently, extensive primary source material has come to light about the organisation and activities surrounding the Maxwell Centenary Celebration in Cambridge. With the move of the Cavendish Laboratory to the new buildings in prospect, the cataloguing and preservation of historic materials have been carried out, during which a number of significant finds were made. These included the Minute Book of the Committee to organise the Maxwell Celebration, the handbooks for the Celebration itself and, perhaps most remarkably, a very early colour film of the ceremonial procession from Corpus Christi College along King's Parade to the Senate House. The film was found in a small, rusting canister during the clear-out of the Cockcroft Lecture Theatre (Fig. 2).

Fig. 2: Canister containing the colour film of the procession on 1 October 1931

Ernest Rutherford, the Cavendish Professor of Physics, called a preliminary meeting to discuss the possibility of holding a Maxwell Centenary Celebration on Wednesday 30th September 1930. The Committee included Will Spens, the University's Vice-Chancellor and Master of Corpus Christi, J. J. Thomson, George Searle, Piotr Kapitsa, John Cockcroft and C. T. R. Wilson. The suggestion that Maxwell should be celebrated met with unanimous agreement. Rutherford 'stressed the desirability' of the University's involvement in the festivities, with Thomson remarking on Maxwell's lack of recognition during his lifetime. Searle suggested that the Large Lecture Room, in which the meeting was held, should be renamed the Maxwell Lecture Room in his honour. The minute also suggests that a centenary celebration would benefit the standing of the University, whilst James Jeans remarked that the celebration ought to 'bring home to the world the practical uses of the mathematical physicist'.

Rutherford also sat on the committee for the Faraday Centenary and suggested that the Maxwell festivities immediately follow the Faraday Celebrations. The dates were fixed for 30th September to 2nd October 1931. The first official committee meeting took place forty-five minutes after the preliminary meeting and a provisional programme was devised.

A remarkable list of lecturers and attendees was drawn up, including representatives of many major national and international learned societies. Because of the deliberately close proximity in time of the three major celebrations, the international representatives could 'kill three birds with one stone.' In a remarkable table in the *Reporter*, there is a long list of the guests and the Cambridge academics who offered accommodation and hospitality in their own homes.

Following the unveiling of the commemorative plaques to both Maxwell and Faraday in Westminster Abbey on the 30th September by J. J. Thomson, the programme of activities began in earnest with lunch courtesy of the Vice-Chancellor in Corpus Christi College on 1st October. The formal procession to the Senate House was filmed in colour to be shown at the end of the following day's proceedings. The inaugural lecture was given by J. J. Thomson followed by tea at Peterhouse. The next morning, lectures were given by Max Planck, Joseph Larmor and Niels Bohr and in the afternoon by former associates of Maxwell, William Garnett, Ambrose Fleming and Oliver Lodge as well as by James Jeans. Einstein was invited but was unable to come, though he contributed to the subsequent memorial volume.

Finally, the Laboratory was host to a display of Maxwell's personal effects and experimental apparatus as well as those of Rayleigh and Thomson (Fig. 3). In addition, there were rooms reserved for demonstrations of current Cavendish research, with exhibitors including Rutherford, Chadwick, Cockcroft, Walton and a number of others.

Fig. 3: A photograph of the 1931 exhibition in what was normally Searle's practical class. The numbered tables corresponded to the Handbook, in which the artifacts on display were explained. The exhibition includes the portraits and manuscripts of Maxwell on the back wall.

As a final entertainment, the colour film had been processed overnight and was shown to delegates in the Cavendish Laboratory after the Celebration Dinner. The film was produced by Thomas Thorne-Baker, of Messrs Spicer Ltd., a company based in Sawston. Thorne-Baker was also charged with reconstructing Maxwell's original three-colour projection of a tartan ribbon, to be shown before the film itself. The film was made using a process called 'Dufay Colour', which had only been invented in the previous year. The result was a colour film lasting just over a minute of the academic guests making their way to the Senate House on 1st October (Figs. 4 and 5). This was a unique celebration of Maxwell's work in the fields of colour and light. The film was professionally digitised in 2019 and is a remarkable achievement.

The film shows the procession from Corpus Christi College down King's Parade with people lining the streets, but with a distinct sense of normality. A window cleaner goes about his business, and people seem to be enjoying the passing show.

It was agreed that the lectures should be bound in a volume published by Cambridge University Press. *James Clerk Maxwell: A Commemoration Volume* (1931) features contributions from all of the above speakers, and also essays by Einstein, Richard Glazebrook, and Horace Lamb. Two striking aspects of the volume are, first, the promotion of Maxwell as deserving much more recognition than he had received during his lifetime, and, second, as a 'Cambridge man'.

It is planned that this unique film of the Maxwell celebration will be made available on-line in the near future.

Fig. 4: A still taken from the beginning of the film, showing the figures of Oliver Lodge and Francis Aston in their doctoral gowns leaving Corpus Christi College as they processed to the Senate House.

Fig. 5: A still from the film. In the background, the window cleaner can be seen going about his business, whilst in the foreground, the 'brilliant blue of Prof. Cabrera's robes being particularly well reproduced' makes Blas Cabrera easily identifiable.

Author Dr Grace Exley

ALEXANDER MUIRHEAD AND HIS CONTRIBUTION TO TELEGRAPHY

CATHERINE BOOTH

Alexander Muirhead (1848–1920) was not only a key figure in the development of submarine cable telegraphy, but went on, in collaboration with Sir Oliver Lodge (1851–1940), to devise and improve the means of sending wireless telegraphic signals (Birse, 2004; Lodge, 1921; Grace's Guide). His name deserves to be celebrated alongside that of Marconi for his contribution to the history of electronic communication.

Alexander Muirhead was born the second son of a prosperous farming family at Salton (or Saltoun) Barley Mill, East Lothian. It seems his father, John Muirhead, was more interested in engineering than farming, and when Alexander was around eight years old, John uprooted the whole family to London. There, John co-founded an electrical engineering company, Warden, Clark and Muirhead, to provide instruments for the telegraphic industry. As a schoolboy, Alexander often visited his father's company, and had the opportunity to meet leading scientists including James Clerk Maxwell and Sir William Thomson (later, Lord Kelvin).

In his early childhood, Alexander had a serious accident which caused him to become lame and partially deaf, and these health problems affected him all his life. At school, his deafness caused others to believe he had learning difficulties, but this was far from the case. From 1863 he was an outstanding student at the prestigious University College School, which he followed by studying sciences at the University of London. He graduated with honours in chemistry in 1869, and in 1870, became a Fellow of the Chemical Society.

Possibly influenced by his father's interests, Alexander pursued his career by, interestingly, studying electrical science at Barts (St Bartholomew's Hospital), for which he was awarded a DSc in 1872. It seemed he made the most of combining medicine with electricity; by attaching wires to a patient's wrists, he succeeded in recording the first electro-cardiogram.

From there he was appointed scientific adviser with his father's company, later called Latimer Clark, Muirhead and Company, where his brother, John, also worked.

Muirhead was a stickler for precise measurement and recording, and looked to determine optimum standards in devices he produced. In 1873, his colleague, Josiah Latimer Clark, invented a form of battery called a Clark cell, which produced a stable voltage. However, it would only work efficiently when kept steady, so was not suitable anywhere there was likely to be instability, nor could it be transported. Movement of the mercury pool at its base was likely to damage the cell and cause changes in its electromotive force. Muirhead devised an alternative configuration of zinc, platinum wire and mercury, resulting in a portable and more reliable standard cell (Muirhead, 1886). For many years thereafter, his company supplied these cells to the Board of Trade and to businesses. He later passed his investigations on standard cells to the National Physical Laboratory, which formed the basis of its work on electrical standards.

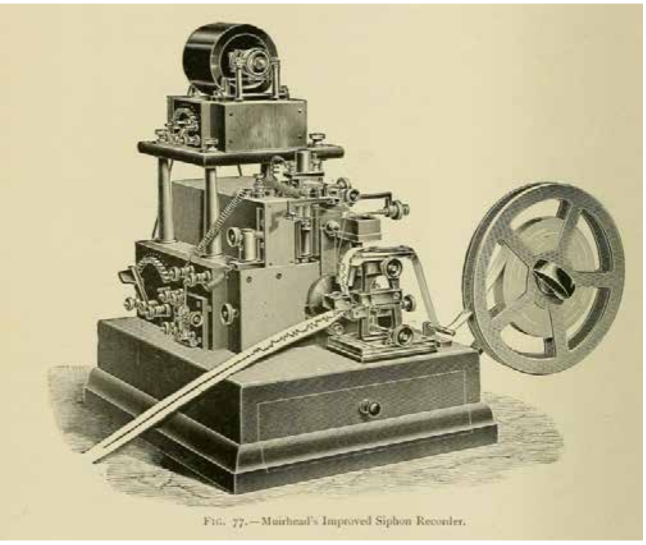
After several attempts, 1866 had seen the first successful installation of a telegraphic cable across the Atlantic, for which credit is largely given to Kelvin. This project was rightly seen as a huge technological advance, and rewarded Kelvin and three others with knighthoods. It also provided the impetus for the development of improved methods of transmitting and receiving signals, attracting the attention of engineers such as the ever-inventive Alexander Muirhead. From around 1875, working alone or with others, he took out a number of patents, many relating to cable telegraphy. One example, from 1875, covered telegraphic accumulators and condensers (Taylor & Muirhead, 1875).

Muirhead also began to look at the efficiency and speed of transmission, again filing various patents. His method of 'duplex telegraphy', developed in conjunction with his brother, John, and Herbert Taylor, was successfully used in France, then for the Madras-Penang cable. A 'duplex' apparatus enabled two signals to be sent simultaneously in opposite directions, using the same conductor. He took this further by developing a 'quadruplex' system, where two signals of differing strengths and polarities travelled simultaneously from each end of the line. Instruments only detected the currents for which they had been designed (Muirhead & Winter, 1878).

Engineers were also looking to improve the instruments for sending and receiving messages. An early receiving device was the mirror galvanometer, improved by Kelvin, which displayed the incoming current as a deflected beam of light. Perhaps its only disadvantage was that at least two operators had to be present to read and note the received signal. Kelvin's siphon recorder, which produced a record of the message on a strip of paper tape, preserved the message, thus removing the need for operators to be on hand. Patents filed by Muirhead in the 1890s and later included improvements in siphon recorders (Muirhead & Edgar, 1900).

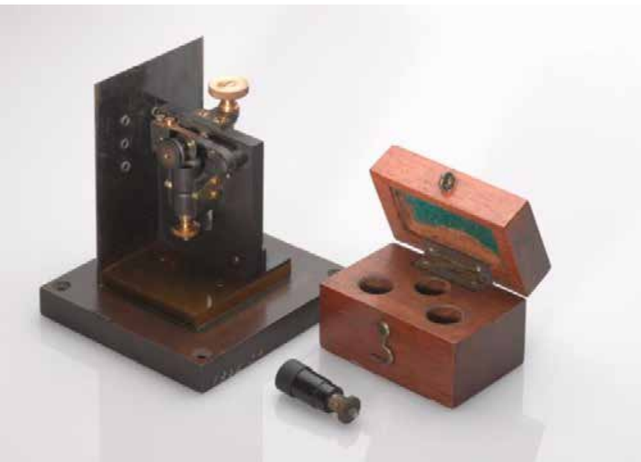
Muirhead gained a reputation as someone knowledgeable in cable technology, and in 1896 was asked to provide crucial evidence to a Commission considering the installation of a cable across the Pacific.

His evidence was enough to persuade the Commission that the scheme was viable.



Muirhead's improved siphon recorder,
as depicted in Charles Bright's book on
submarine telegraphs (Bright, 1898)

In 1894, Muirhead was present when Oliver Lodge delivered a lecture on Hertzian waves at the Royal Institution, which demonstrated his experiments on signalling through space (Rowlands & Wilson, 1994). Sparks from an induction coil led to signals being detected a distance away by a 'coherer'. This instrument, originally called a 'radio-conducteur', was a device invented in 1890 by French physicist Édouard Branly (1844–1940). By 1894, Branly had improved his design which by then consisted of a tube containing two electrodes with metal filings between them. The signal caused the filings to cling together creating a strong electric current which could be seen using a mirror galvanometer. A disadvantage was that the coherer needed to be tapped after each time to reset the filings. Lodge recognised that more powerful apparatus would allow signals to be transmitted over much longer distances. It should be noted that it was two years after this demonstration that Marconi took out his own patents on wireless telegraphy, also using Hertzian waves and a coherer.

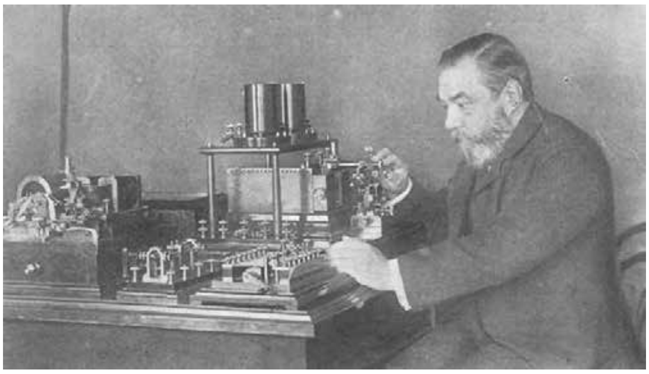


Wheel or steel-disc coherer (thin-film detector), 1902.
Science Museum Group Collection, available online
(CC BY-NC-SA 4.0 Licence)

We can imagine the interest which Muirhead took in Lodge's demonstrations, and indeed his inventive brain set to work on improving the instruments involved in such communications. Lodge was the scientist with the ideas, but Muirhead undoubtedly was the practical engineer able to work out how to bring them about. Over the following five years he and Lodge filed joint patents describing improvements and modifications in coherers and other associated pieces of apparatus, and they formed the Lodge-Muirhead Wireless Syndicate in 1901. In 1904, it was this Syndicate which was successful in establishing wireless communications over the 300 miles between the Andaman Islands and Burma. This time, they used a wheel or steel-disc coherer – a thin-film detector – likely to be similar to the design in the above photograph from the Science Museum collections which did not need to be reset.

At an annual 'conversazione' of the Royal Society in 1906, Lodge and Muirhead displayed a portable wireless telegraph apparatus, which had been proved to work over 50 miles on land, or 150 miles at sea (*Scientific American*, 1906).

One major problem they addressed was tuning – to disentangle the message required from all the 'noise' from other transmitted signals. For military use especially, this ability was essential. Methods which Lodge and Muirhead used to solve the problem were described in their joint article (Lodge & Muirhead, 1909).



Alexander Muirhead adjusting his 'delicate coherer'; copyright, English Heritage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MUIRHEAD & CO.,

ELECTRICAL ENGINEERS

AND

CONTRACTORS.

Illustrated Price List.

Muirhead & Co., Illustrated price list

Recognition of his achievements came to Muirhead in his election as Fellow of the Royal Society in 1904.

It seems, however, that Lodge and Muirhead did not have either the motivation nor the financial backing to develop their ideas commercially, and the Lodge-Muirhead Wireless Syndicate, including their patents, was bought out by Marconi in 1911. Marconi was fortunate to have influential connections and family wealth which allowed him to exploit these ideas in conjunction with experiments he was carrying out himself.

Muirhead had set up his own firm, Muirhead and Company, around 1890. This was a manufacturing company which produced a wide range of scientific equipment and electrical devices including dynamos, lamps, switches, insulators, condensers, lightning conductors and Morse keys (Muirhead & Co., 1893). He moved the business nearer his home in Bromley in 1896, and it became a major local employer. The company continued to operate right through the 20th century and beyond, having a high reputation for the precision and accuracy of the instruments it produced. Eventually it was reformed as Muirhead Aerospace, also operating as Muirhead Avionics, which continues to manufacture products for the military and aerospace industries.

Copyright: plaquesoflondon.co.uk

In his personal life, Alexander Muirhead married Mary Elizabeth Blomfield in 1893, and they settled at 20 Church Road, Shortlands, Bromley, where he was to live for the rest of his life. They had no children. A blue plaque now marks the house. He died in December 1920, and is buried in Norwood Cemetery. He left major legacies to both the Royal Society and the Church of Scotland.

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Acknowledgement

This article first appeared in a slightly different form in Transmitting, the journal of the Museum of Communication:

Booth, C. 'Inventive Scottish electrical engineer, Dr Alexander Muirhead FRS (1848–1920), and his contributions to telegraphy', Transmitting 100, August 2022.

Author

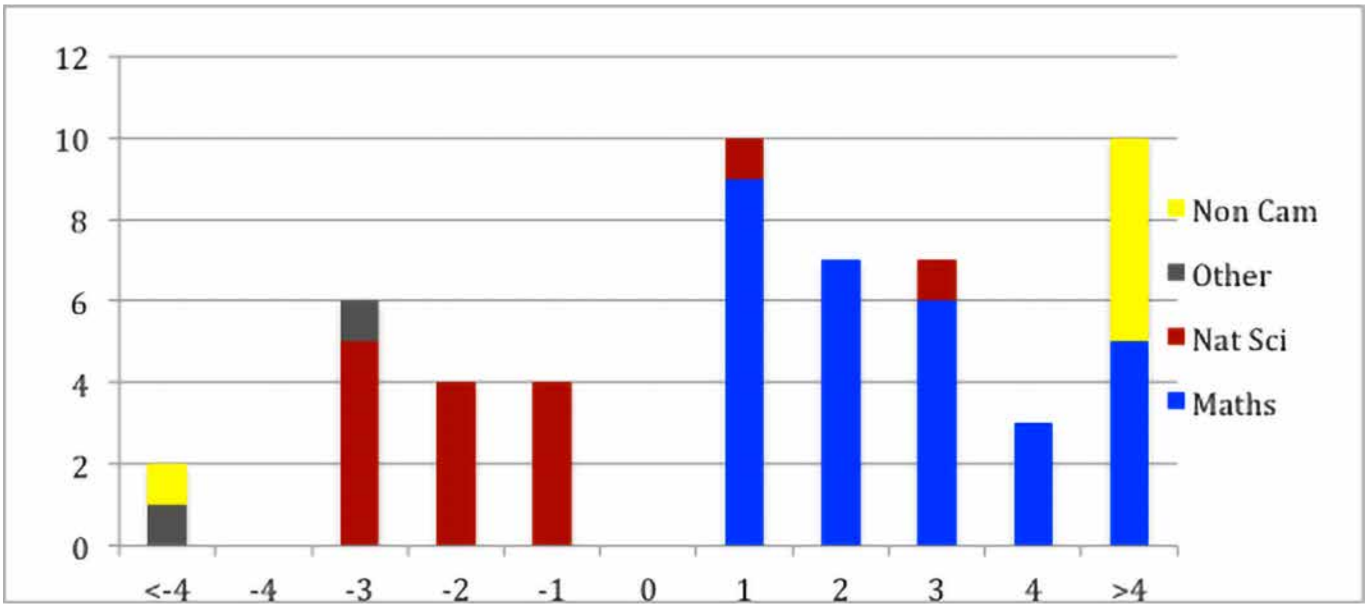
Catherine Booth, Trustee and former Secretary of the James Clerk Maxwell Foundation

EXPERIMENTALISTS IN MAXWELL'S CAVENDISH

Isobel Falconer (from a blog of 14 July 2016)

I was very excited … to discover that a colleague was descended from Charles Heycock (1858–1931), who more or less founded Materials Science in Cambridge. However, Heycock's significance for me is that he entered, and published from, Maxwell's Cavendish Laboratory aged 17 while still at school. He exemplifies Maxwell's open-door policy at the Cavendish (provided you were male).

This prompted me to post up an analysis of those we know were doing experimental work in Maxwell's Cavendish, plotted against their year(s) pre- or post-graduation and their subject. The results are remarkable and show very clearly the impact of the Cambridge system on experimenter numbers.



On the chart, zero represents their graduation year. Thus, -1, -2… etc are undergraduates at one, two, … etc years before graduation. 1, 2, … etc are postgraduates at one, two, … etc years after graduation.

The majority of postgraduates were mathematicians. They were hanging around Cambridge seeking research topics that would earn them a College fellowship in a year or two's time. There was no such incentive for Natural Science postgraduates. In 1870 the *University Reporter* commented that some colleges would consider themselves 'guilty of extravagance' in appointing scientific fellows.

Conversely, the undergraduates were mostly studying Natural Sciences. From 1874 on a practical exam in physics had been included in the Natural Sciences course, providing an incentive for students to take an interest in experimental physics – though it is important to note that the students included in the chart here were doing research not a practical physics course. No mathematicians are recorded as doing experimental work while undergraduates. Although physical subjects had been added into the Maths Tripos in 1873, students very rapidly realised that there was so much choice in the question paper that they had no need to study physics in order to do well. Nor did they need practical work. Physics was removed again in 1882 to the postgraduate Part III of the Maths Tripos.

Thus the chart echoes George Bettany's lament to *Nature* in 1874,

> 'The great hindrance to the success of the Cavendish Laboratory at present is the system fostered by the Mathematical Tripos. The men who would most naturally be the practical workers in the laboratory are compelled to refrain from practical work if they would gain the best possible place in the Tripos list. Very few have courage so far to peril their place or to resign their hopes as to spend any valuable portion of their time on practical work… For a man to do practical work in physics at Cambridge implies considerable exercise of courage and self-sacrifice.'

And what of Charles Heycock? He is the "non-Cambridge" undergraduate at < -4. He was 17 when he worked in the Cavendish with Arthur Clayden (an undergraduate) on the spectrum of indium. He didn't enter the University for another year, and subsequently read Natural Sciences, graduating with a first-class degree in chemistry and physics. He became a FRS and founder of Cambridge's Department of Materials Science.

THE BROADER CONTEXT OF JAMES CLERK MAXWELL'S MEASUREMENT OF ELECTRICAL RESISTANCE

PAUL QUINCEY

Introduction

Alessandro Volta's invention of the electric battery in around 1800 (Figure 1) triggered many of the advances that led to the modern world. Previous work on electricity, for example by Henry Cavendish or Benjamin Franklin, could only explore the transient phenomena available from static electricity. Batteries provided a much steadier voltage and power source for laboratory experiments, allowing electricity and electromagnetism to be properly understood, and practical applications to be developed. Batteries were soon used for electrolysis as well, for example by Humphry Davy at the Royal Institution in London, producing many new chemical elements.

Figure 1: A voltaic pile made by Alessandro Volta and presented to Michael Faraday in 1814. Photo credit: the Royal Institution.

This new quantitative study of electrical phenomena raised major questions for the world of measurement which were not fully resolved until 2019. Previously, the scientific measurement units that needed international discussion and agreement were for mass and length – time and angle units being much easier to define. Rather quickly, this small set expanded to include charge, current, voltage, resistance, capacitance and many other quantities. The problem came at several levels: scientists and engineers needed to make measurements that that they could compare with each other; theoretical physicists needed a clear framework within which to set out their equations; and underlying both of these, often forgotten in the rush, was the question "What is going on when electrical and magnetic phenomena take place?" Nobody will be surprised to hear that far-reaching decisions were made when the understanding of the subject was still very vague.

One insight that was appreciated early on was that only one new unit, at most, needed defining. If the basic relationships between quantities, like

$$\textit{voltage} \times \textit{current} = \textit{power},$$

and

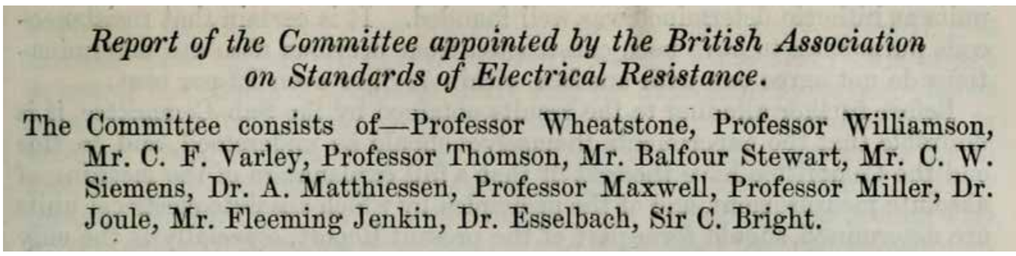
$$\textit{current} \times \textit{resistance} = \textit{voltage},$$

are treated as fundamental, pinning down one electrical unit pins them all down. The idea of having a unit *system*, rather than a large set of independent units, was established. As well as reducing the number of unit definitions, this avoids the need for arbitrary conversion factors to appear within equations.

The focus on electrical resistance

Electrical resistance soon took on a central role, because it was frequently measured, for example along telegraph cables, and because standard resistors, in the form of a coil of wire, were relatively stable and simple to make compared to other electrical quantities. But what rough size should the unit of resistance be, how should it be defined, and how could this unit be realised in practice? It was time to set up a committee.

The British Association for the Advancement of Science (B.A.) rose to the challenge in 1861. By 1863 the committee reporting on 'Standards of Electrical Resistance' contained James Joule, William Thomson (later Lord Kelvin) and James Clerk Maxwell (Figure 2).



Report of the Committee appointed by the British Association on Standards of Electrical Resistance.

The Committee consists of—Professor Wheatstone, Professor Williamson, Mr. C. F. Varley, Professor Thomson, Mr. Balfour Stewart, Mr. C. W. Siemens, Dr. A. Matthiessen, Professor Maxwell, Professor Miller, Dr. Joule, Mr. Fleeming Jenkin, Dr. Esselbach, Sir C. Bright.

Figure 2. The B.A. committee members in 1863.

Resistance could have been treated like mass in the metric system, which was originally defined in terms of the density of water. A suitable material, like pure mercury, could be given a defined resistivity, so that a known resistance could be made by having a known length and cross-section of mercury. If that was too variable in practice, a well-chosen coil of wire, like a reference mass, could simply be declared to have a resistance equal to the resistance unit, at a specified temperature.

But the B.A. committee went down another path, led by an appealing but ultimately unhelpful and false idea, strongly advocated by Maxwell, that all physical quantities could be considered as combinations of mass, length and time. In effect, this was a declaration of faith that electrical and magnetic phenomena would prove to be mechanical in origin, in the same way that the mysterious fluid that carried heat, known as caloric, had proved to be. It is perhaps better seen as a strong preference by theoretical physicists to avoid any new physical constant being introduced into equations, so that the force between two charges, q_1 and q_2, separated by a distance d could be written simply as, for example:

$$F = \frac{q_1 q_2}{d^2}.$$

In 1832 Carl Friedrich Gauss had shown that you could measure the intensity of the Earth's magnetic field using only units for mass, length and time, with its units taking the form $m^{-1/2}\ kg^{1/2}\ s^{-1}$. This was ingenious, as well as having the practical benefit of avoiding the need to invent any new units, but it required the assumption that an electrical current is the square root of a force. Of course, we now know that a current is not the square root of a force in any physical sense, and that Gauss's measurement method worked by determining a quantity *proportional* to magnetic field intensity. We would now say that Gauss's magnetic field was the SI-defined magnetic field divided by

$$\sqrt{\frac{\mu_0}{4\pi}},$$

where μ_0 is the magnetic constant. Gauss, and especially his colleague Wilhelm Weber, showed that all electrical and magnetic quantities could be expressed as combinations of mass, length and time in two different ways – termed 'electromagnetic', which in modern terms set μ_0 equal to 4π, and 'electrostatic', which set the electric constant ε_0 equal to $1/4\pi$ – and they devised methods for measuring electrical and magnetic quantities accordingly. The B.A. committee chose to follow Weber's 'electromagnetic' method for resistance, which gave it the units of velocity, m/s. The 'electrostatic' route would have given it units of s/m.

In this way they could avoid introducing any arbitrary new electrical definition, such as the resistivity of mercury, which would inevitably lead to long international discussions. The methods were called 'absolute', because they only required measurements of mechanical quantities, not comparison with an electrical or magnetic standard. The committee's task was to design and build apparatus that could measure the resistance of an object in units of m/s with high accuracy.

Maxwell's measurements of resistance

Their equipment, shown in Figure 3, was designed by Thomson, and the experiments were carried out by Maxwell and his colleague Fleeming Jenkin in 1863 at King's College London, where Maxwell was Professor of Natural Philosophy between 1860 and 1865.

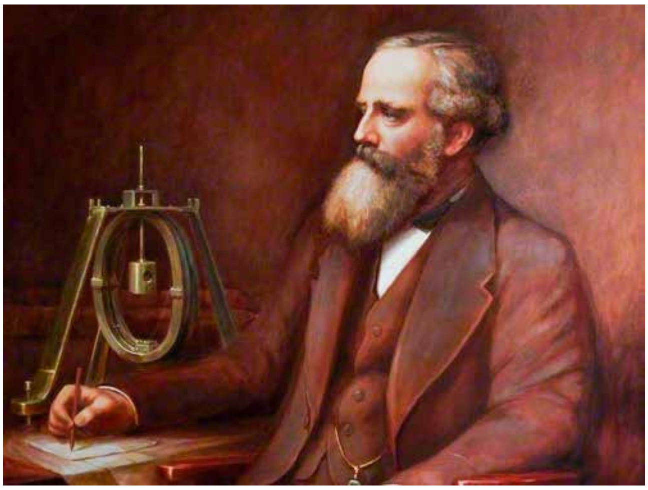


Figure 3: Portrait of Maxwell with the rotating coil apparatus. This was painted by R. H. Campbell in 1929, 50 years after Maxwell's death. The original is in the archives of the Institution of Engineering and Technology, London.

The equipment worked something like this. The objective was to measure the resistance of the circular coil. This was rotated around its vertical axis at a steady rate of about 7 times a second – the frequency was made easier to determine by a bell ringing every 100 rotations. The movement induced a voltage within the coil because of the Earth's magnetic field. This voltage created a current within the coil, which of course depended on its resistance. And the induced current created a magnetic field that could be compared with the Earth's magnetic field by observing the deflection of a small magnet suspended at the centre of the coil. In this way, with a lot of skill and care, a quantity proportional to resistance could be measured in m/s.

After five months of refining the method, they found the day-to-day variation in their results over the last three days was 0.4%. With hindsight, this was not a sound basis for an important decision, but the committee concluded that their proposed method was viable, and declared that the resistance of a particular coil of 'German silver' wire, an alloy of copper and nickel, was 107,620,116 m/s.

Because the values of useful resistances were impractically large in units of m/s (and even worse in cm/s), they recommended that the resistance unit should be defined as 10,000,000 m/s. This eventually became called an ohm. Standard resistance coils, ultimately certified in ohms by this method, were made and distributed to researchers such as Michael Faraday.

The next 20 years

The work at King's would soon be checked, as other countries made their own measurements of the standard coils using their own 'absolute' methods. They obtained results that differed by up to 2%, which would be good enough for most everyday purposes, but were not satisfactory in the worlds of research or advanced engineering. Maxwell had taken the apparatus with him when he moved to Cambridge, where he died prematurely in 1879. Lord Rayleigh, Maxwell's successor as Cavendish professor, repeated the measurements, making improvements to the rotating coil apparatus and re-examining the method of calculating the results. In 1881 he found that the original resistance results were too low by 1.1%. Using new equipment of different designs, by 1883 the discrepancy was consistently found to be 1.3%. Perhaps surprisingly, the cause was mainly attributed to the theoretical treatment of the results, specifically the contribution of the self-inductance of the coil.

This provided an unfortunate example of a unit definition being chosen before it could be realised accurately enough in practice. Scientists and engineers had to deal with some pragmatic standards of resistance such as the 'B.A. Committee' ohm and the 'International' ohm, both of which differed significantly from the 'true' ohm, until more accurate methods were developed.

The next 160 years

When it eventually became clear that electricity was not a mechanical phenomenon, a unit for electric current (the ampere) was added to the base units for mass, length and time. The SI ampere, and hence all SI electrical and magnetic units, was defined by setting μ_0 to be exactly $4\pi \times 10^{-7}$ N/A^2, the 10^{-7} following from the B.A. choice of 10,000,000 m/s for the ohm. The units N/A^2 can also be written as Ω/(m/s), showing why forcing μ_0 to be a dimensionless number makes you think that a current is the square root of a force, and a resistance is in some sense a velocity. We can see that this move was a direct continuation of the 'absolute' approach used by Maxwell, even though the underlying philosophy was very different.

This definition stayed in place from the SI's creation in 1960 until 2019. In that year, the SI definition changed from assigning an exact value for μ_0 to assigning an exact value for e, the elementary charge, marking a clean break from the long sequence of fixed values for μ_0: from 4π (by Gauss), to $4\pi \times 10^{-7}$ (by the British Association), to $4\pi \times 10^{-7}$ N/A^2 (in the original SI), to the experimentally determined $1.256\,637\,061\,27 \times 10^{-6}$ N/A^2 (in the current SI). The change was made to give h/e and h/e^2 fixed values in SI units, where h is the Planck constant, which was also given an exact value in 2019. This allowed measurement techniques based on quantum physics, such as Josephson voltage standards and Quantum Hall Effect resistance standards, to be used most effectively.

It is illuminating to compare the process followed to fix the value of e in 2019 with the resistance work in 1863. For a start, e was not measured directly. The value of h/e^2 was known to better than a part in a billion from measurements of the fine structure constant, and h could be measured more accurately than e, so that the value of e was determined from measurements of h.

In the years leading up to 2019, several new measurements of h were made using one of two entirely independent methods, based on either a Kibble balance or a sphere of silicon-28, and these all agreed to within a few parts in 100 million. Even then there was some doubt within the relevant committee that this agreement was close enough to justify a change to the definition, but it was formally decided in 2018 that e would be fixed as exactly $1.602176634 \times 10^{-19}$ coulombs (see www.nist.gov/si-redefinition). The large number of figures is designed to ensure maximum continuity with earlier measurements. It seems very likely that the long saga of defining measurement units for electrical and magnetic quantities, including resistance, has reached its final point.

Further reading

Grant, P. M. & Thompson, J. S., 'Maxwell's contribution to standardising the unit of electrical resistance', Newsletter of the James Clerk Maxwell Foundation 14 (Spring 2020), available at www.clerkmaxwellfoundation.org/Newsletter_2020_Spring.pdf

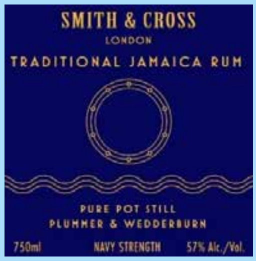
Reports of the Committee on Electrical Standards, Cambridge University Press, 1913, available at dn790003.ca.archive.org/0/items/reportsofcommittoobrituoft/reportsofcommittoobrituoft.pdf

Author

Dr Paul Quincey is fully retired after a career at the National Physical Laboratory. The article is adapted from one in a series on the history of scientific measurement at www.metrologicalhindsight.wordpress.com.

SUGAR, RUM AND SLAVERY
PART 1: MAXWELL'S AUNT ISABELLA AND THE WEDDERBURNS

Chris Pritchard



Introduction

Afficionados of fine rum will likely look out for the name 'Wedderburn' on the label. Wedderburn-style rums are distilled in copper pots over a relatively short period, characteristically heavy-bodied and high in esters. The Wedderburns, whose name they carry, were a dynasty of rich Scots who owned or managed sugar estates, especially in Jamaica, estates that made their profits on the lashed backs of enslaved people.

When just ten years old, while his father remained at their country home in Dumfriesshire, James Clerk Maxwell was sent to live with his Aunt Isabella, his father's sister, to enable him to attend the Edinburgh Academy. Located at 31 Heriot Row, just around the corner from where he was born, Isabella's home was one of the finest houses on one of the finest streets in Edinburgh's New Town. The house had belonged to Maxwell's father's family, the Clerks, but Aunt Isabella had married James Wedderburn, whose family was even wealthier. With their growing family and James's growing reputation as a lawyer, they took full ownership around 1820. Aunt Isabella was born Isabella Clerk, but when James arrived to stay with her, she was the already-widowed, Isabella Wedderburn.

Isabella Wedderburn, by Henry Raeburn (c.1820), Yale University, Public domain

Sugar, indentured labour and slaves

The transatlantic slave trade was nurtured by the Spanish and Portuguese from the early sixteenth century. In the first half of the seventeenth century the English arrived in Barbados, promptly imported sugar plants from Brazil and set about its cultivation. Unlike in Brazil, the plantations became efficient by handling the production of sugar as well as its cultivation (Scanlan, p.30). But to maximise production a very large labour force was required. So began the indentured labour schemes that offered poor white men and women from England and Ireland a demanding route to betterment. They were provided with passage to the Caribbean in return for seven to nine years of servitude. Yet there were still too few men to work the sugar cane and so the market for black African slaves began to expand rapidly. Indeed, with its legitimisation through the establishment of the Barbados Slave Code, passed by the island's parliament in 1661, the number of slaves in Barbados grew to 50,000 within forty years.

Although slaves and indentured labourers were often treated in similarly brutal ways in the Caribbean, their status in law was different. Indentured labourers had access to the law, though the judiciary was largely controlled by the estate owners. What was different was that race was not the predominant feature of the indentured labour schemes which existed before, at the same time as, and after slavery.

England took Jamaica from the Spanish in 1655 and proceeded to clear the land and apportion it into manageable units for the production of sugar. Padraic Scanlan's book *Slave Empire* provides a vivid description of the processing of cane sugar. Scanlan writes (p.69):

> Sugar plantations centred around a single mill or series of mills where the cane juice was boiled and clarified in enormous copper vats. … The average eighteenth-century mill could produce between 300 and 350 gallons of cane juice each hour, while newer mills introduced at the turn of the nineteenth century could increase the yield to as much as 500 gallons an hour. … The sugar was then cured in hogshead barrels … with holes bored in the bottom. Molasses dripped from the bottom of the barrel and collected in vats. The dry, cured brown sugar left at the end of the process was called *muscovado*. … Although molasses was shipped out of the sugar islands alongside sugar, most estates also had a distillery to turn excess molasses into rum. Distilling also required industrial

gear, including two copper stills, usually one up to 1,200 and the other up to 600 gallons, as well as cisterns and fermenting vats.

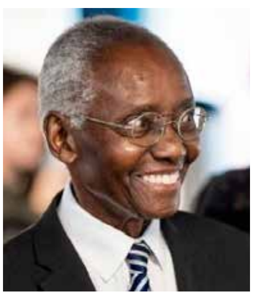
Jamaica has an area 45 times that of Barbados, so this was sugar production on a whole new scale and with it the demand and supply of African slaves. Using the Barbados Slave Code as their model, the Jamaican Slave Act of 1696 was drafted to lay down what slaves and their owners could and couldn't do; it codified the means and extent to which slaves could be mistreated. By the middle of the eighteenth century, the soils of the Jamaican estates were among the most fertile, productive and profitable in the world. Sugar consumption in Britain rose fourfold between 1710 and 1770, during which time sugar became the most valuable product in the world (Scanlan, p. 33). Profits boomed, so that by the second half of the eighteenth century, with the average net worth of a person in England and Wales at just £42, that of a Jamaica estate owner was £1042 (Scanlan, pp. 30-31).

Towards the end of the century, there were 30,000 white Europeans and 200,000 enslaved black Africans and their descendants. Plantations had grown larger or been amalgamated as they were bought up so that the number of owners had decreased, and greater wealth and power rested with fewer individuals. A third of the plantations were in the hands of absentee owners. The owners of the other two-thirds resided in Jamaica, normally on one of their estates, though many employed a manager or 'attorney' for each estate. This is where the Scots come in, for following the Act of Union, it was the Scottish universities rather than Oxford and Cambridge that turned out ambitious, well-educated young men keen to travel and make their fortunes. Jamaica was soon awash with Scottish surnames and Scottish placenames; perhaps a third of this huge island was under the control of Scots, albeit under the Union flag. 'The attorney trade was ... dominated by educated Scots' (Scanlan, p. 85). Under them were the overseers, often brutal, physically with the men, sexually with the women. The Scots developed 'an unusually harsh reputation in the colonies for their treatment of slaves' (Whyte, p. 187).

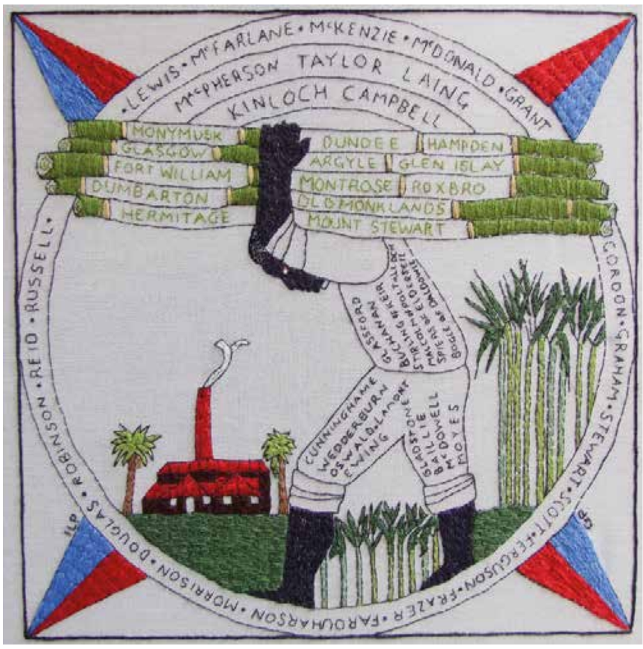
A decade or so ago, a project was undertaken to celebrate 'Scottish heritage and culture, the people and places which connect Scotland to its global diaspora' through the design and embroidery of tapestry panels. The idea behind the project is explained at its website www.scottishdiasporatapestry.org:

> 'Scots have migrated all over the world and have often had a profound impact on the areas where they settled. This project brought together stories from more than such communities, documenting their Scottish connections in more than 300 embroidered panels. It is a remarkable and heart-felt homage to the determination, courage and achievement of Scottish migrants and their descendants across the centuries.'

Panel JM02, below, features the names of Scottish plantation families in Jamaica. It was designed and embroidered by Sir Geoff Palmer (1940–2025) and his daughter. (Sir Geoff was a member of the Windrush Generation. He went on to become Scotland's first black professor, and chancellor of



Heriot-Watt University.) The name to note here is on the right thigh: WEDDERBURN.



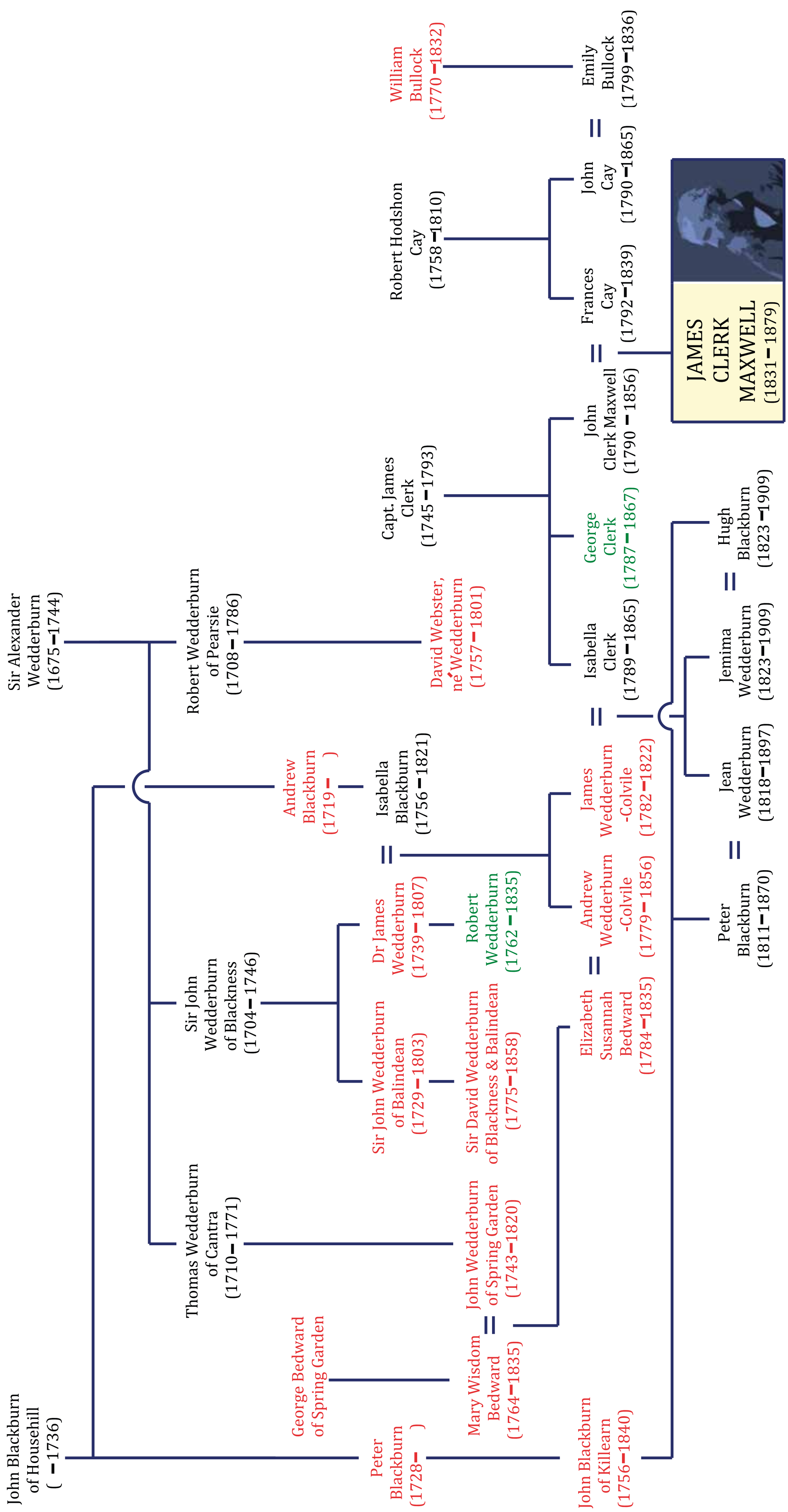
Through marriage, the Wedderburns make up one branch of the paternal side of James Clerk Maxwell's family tree. In fact, there are so many Wedderburns that it is a challenge to draw the inter-relationships in a clear way. It is only by leaving out many of them that it is possible to focus on those engaged in sugar, rum and slavery, whose names and dates are shown in red.

Sir John Wedderburn of Blackness and sons

One line of the family comes through Sir John Wedderburn (1704–1746), 5th Baronet of Blackness, a Jacobite who fought and was captured at Culloden. Taken to London, he was found guilty of treason and hanged, drawn and quartered at the Surrey Gallows on Kennington Common, the South Bank's equivalent to Tyburn, north of the Thames. The Common was always a place of leisure activities – cricket, at the Oval, today, cricket and executions in the eighteenth century. Upon his sentencing, Sir John's estates in Perthshire were lost to the crown. His disgraced and impoverished wife, Jean Fullerton, lived for another twenty years, but their sons with their tarnished surname, chose to distance themselves from Scotland's shores and their collective shame. John and James, Alexander and Peter, ventured to the Caribbean to seek their fortune from sugar production. The first two are particularly important to the Wedderburn family history.

As we shall see, the practice of naming sons after their fathers, so prevalent in these times, means that names such as James and David being used repeatedly within families, makes for a genealogist's nightmare. Sir John Wedderburn of Blackness's eldest son was Sir John Wedderburn of Balindean (1729–1803). He was the first to made a break with Scotland, working his passage on a ship bound for Jamaica. He was quickly followed by the other brothers. Though having no relevant qualifications, John set himself up as a surgeon. At the same time, he unexpectedly came into money left to him by a great uncle. So successfully did he invest this money in sugar estates that within twenty years John owned more land and more slaves than anyone else on the island. Many 'sojourners' – as they were dubbed, for they had no intention

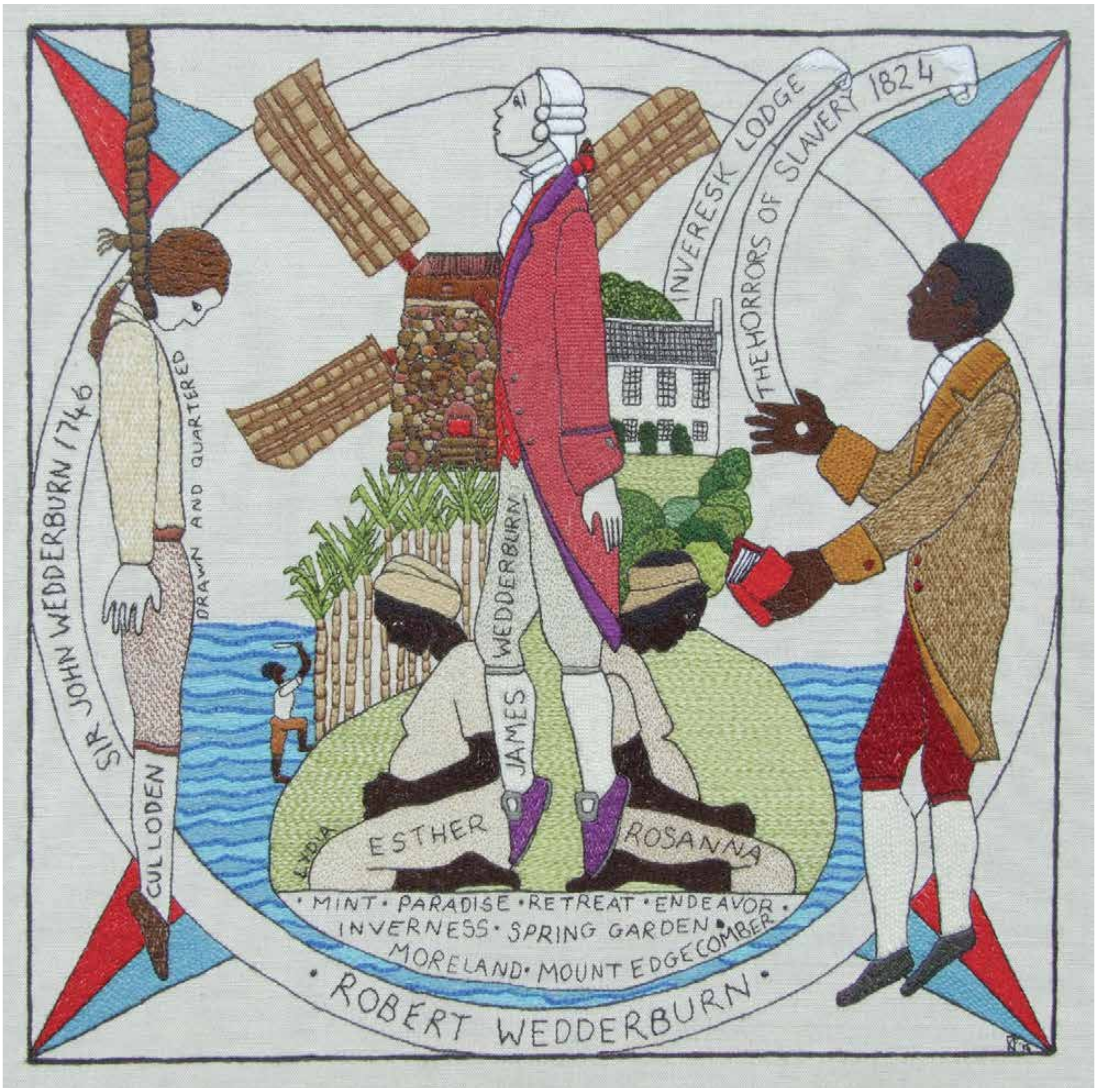
A partial family tree, emphasising Maxwell's father's line, especially the Wedderburns



Members of the extended family of James Clerk Maxwell who were slave owners, plantation attorneys or who were generally pro-slavery are given in red. Maxwell and others deemed neutral or whose views were never stated explicitly are shown in black. Those who were pro-abolition are shown in green.

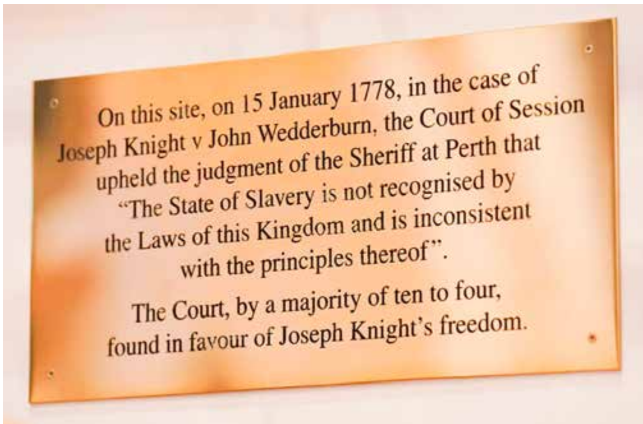
of settling in the Caribbean – died in Jamaica or returned home with only modest financial gains or substantial losses. Indeed, John's two youngest brothers died in Jamaica well before their fortieth birthdays, Alexander in 1764 and Peter in 1773.

But Sir John Wedderburn made a fortune and so was able to sail home to Scotland in the late 1760s to live in prosperity and luxury at his newly-acquired property and land at Balindean (now Ballindean) between Perth and Dundee.



Panel JM03, devoted exclusively to the Wedderburns

Sir John Wedderburn of Balindean continued to be involved in the management of sugar plantations and their slaves, working with his brother Dr James Wedderburn in regard of the Blue Castle and Glenisla estates from 1780 and purchasing the Blackheath estate in 1802, all in Westmoreland Parish at the western end of the island. Sir John's eldest son, James Wedderburn of Penge Place (1772–1815), not shown on the family tree, spent most of the first decade of the nineteenth century in Jamaica but was not successful and returned home. During this time, it was another son, David Wedderburn (1775-1858) who inherited Sir John's land and slaves in Jamaica.



Plaque unveiled by Sir Geoff Palmer at the Court of Session in 2022 to mark Joseph Knight's successful fight to have slavery pronounced inconsistent with Scots Law.

We have not quite finished with Sir John, for this proponent and financial beneficiary of slavery inadvertently furthered the abolitionist cause. When he returned to Scotland he brought his slave servant, Joseph Knight, with him. But Joseph wasn't content with his station in life in eighteenth-century Scotland and made a bid for freedom through the courts. The argument put by his advocate that 'no man is by nature the property of another' was upheld at the Court of Session in Edinburgh in 1778, establishing through this incredibly important judgement the principle that slavery has no basis in Scots Law. This must have left Sir John a bitter man for he devoted the rest of his life to upholding the 'rights' of slaveowners.

John's brother, James Wedderburn (1739–1807) had also sought his fortune in Jamaica, again initially setting himself up as a doctor. In fact, he is often referred to as Dr James. He too bought land and slaves and profited greatly from sugar production. James fathered five children with slave-housekeepers, three with Rosanna, and two with her successor, Esther. The images of the two women, heavy with child, are depicted in panel JM03. James returned to Scotland in 1773, taking his children by Esther with him. The following year he married Isabella Blackburn (1756–1821), daughter of the banker, Andrew Blackburn, who was heavily involved in the tobacco trade, which of course was also heavily dependent on slave labour. They settled in at Inveresk on the outskirts of Musselburgh where to this day the two most prominent roads carry the Wedderburn name. With Isabella's dowry came the additional name of Colvile, so that the family became the Wedderburn Colviles. Isabella's father conferred on her his Glenisla and Blue Castle estates in Jamaica, including the enslaved people who worked the sugar cane.

We get a real insight into the colourful lives of plantation owners from the details of Dr James Wedderburn's will. In it he provided annuities for a number of immediate relatives, as well as £5000 (about £440,000 today) for each son. But he also left 100 guineas for his cousin's widow, Mary Wisdom Wedderburn (née Bedward) to buy a mourning ring, and £1200 for Mary's daughter, Elizabeth Susannah Wedderburn, increased by a further £5000 under a codicil. In addition, the executor of the will was charged with buying slaves to be bequeathed:

- two new slaves to be bought for his cousin Peter Dunbar and two each for in-laws John and Alexander Blyth
- 'unto a Mulatto Child daughter of my negro Wench named Fanny four new negroes'
- 'unto a quadroon child named Lydia supposed to be mine by a Mulatto Woman named Hannah' a piece of land adjacent to the Blue Castle estate, plus 'two negroe Girls named Nancy and Christmas and also eight new Negroes to be purchased'

The concept of buying slaves to ensure that relatives are adequately served after a person's death adds another layer of obscenity onto already obscene practices, but it appears that James Wedderburn saw this as perfectly appropriate.

John Wedderburn of Spring Garden

Now we follow another line in the Wedderburn family tree, down from Thomas Wedderburn of Cantra (1710–1771), a brother of Sir John Wedderburn of Blackness and hence a cousin of John and James. Three of Thomas's sons went to Jamaica, Alexander in 1760, John in 1766 and James in 1768. We are concerned here with John, usually referred to as John Wedderburn of Spring Garden (1743–1820). When John went to Jamaica he was in his early twenties, commissioned as the Governor's aide-de-camp. Through his financial acumen and a favourable marriage, he became the owner of several estates, worth a fortune collectively: Spring Garden, Mount Edgecombe, Paradise, Retreat, Moreland, Blue Castle, Jerusalem, Prospect, Hill's Mountain, Burnt Savannah and Mint. He also owned a succession of smart homes in Mayfair, Bloomsbury and Fitzrovia, conducting trade with the Caribbean as chief partner from 1801 to 1820 in what we refer to below as the 'House of Wedderburn'.

In 1782, John Wedderburn married Mary Wisdom Bedward (1764–1835), the daughter of George Bedward of Spring Garden who managed his estate with undue cruelty. This was a very valuable estate to inherit and so the marriage was thought especially propitious. John and Mary's eldest daughter, Elizabeth Susannah, was born on the Blue Castle estate; she would later marry her second cousin, Andrew Wedderburn Colvile, the subject of the second part of this article.

The 'House of Wedderburn'

While members of the Wedderburn family in Jamaica conducted business on an individual level on the island, they also functioned in a collective sense through their trading house in London. From some point in the mid-eighteenth century, a firm of East and West India merchants owned by brothers James and John Webster conducted business from 35 Leadenhall Street in the City of London. 'There can be little doubt that the Wedderburns in Jamaica and the Websters in Leadenhall Street were able to do business with mutual advantage, and that gradually their interests became more and more closely identified' (Wedderburn, p. 441). David Wedderburn (1757–1801), a nephew of Sir John Wedderburn of Blackness, went to work for the Websters in 1772. Upon the death of James Webster in 1789, he became a partner on condition that he take the surname Webster, and the same year, John Wedderburn of Spring Garden joined the firm. In the mid-1790s, they were joined by another David Wedderburn (1775-1858), the eldest son of Sir John Wedderburn of Balindean, later a successful administrator as Deputy Postmaster-General for Scotland. With the deaths of the original Webster brothers, the firm of Wedderburn, Webster & Co. was essentially run by Wedderburns. John Wedderburn of Spring Garden became the senior partner in 1801, at which point there was a major reconfiguration of the company's assets, and continued in that position until 1820.

Between 1801 and 1820, while John Wedderburn of Spring Garden was senior partner, the 'House of Wedderburn' in Leadenhall Street 'both reached its zenith and began to decline' (Wedderburn, p. 443). Andrew Wedderburn Colvile, son of Dr James Wedderburn (Colvile) had joined the firm in 1798 as a partner with an annual salary of £1000 and by 1803 he was an active and influential member. A family outsider, Alexander Seaton, joined in 1810, though some 80% of the firm of Colvile, Wedderburn & Co. remained in Wedderburn hands. Later still, the owners were whittled down to Andrew Wedderburn Colvile and Alexander Seaton, then from 1836 to just the former.

At one time or another the 'House of Wedderburn' or family members owned a huge number of sugar estates, many of which have already been listed in relation to John Wedderburn of Spring Garden, but to them we may add Trelawny, Newfound River, Blackheath, Blackness, Three Mountains River, Berricon, Carawina, Colvile, Green River and Fontabelle (all in Jamaica) and Belle Vue (in present-day Guyana). They also owned or part-owned several ships trading to the Caribbean, the accounts for 1801 listing the Arniston, Jamaica Planter, Melville Castle, Hanover, Symmetry and Westmoreland. One of the sons of Dr James Wedderburn, Peter Wedderburn Ogilvy (1781–1873), not featured on the family tree above, captained the Arniston for the 'House of Wedderburn' on its sixth voyage from Portsmouth to China and back to Gravesend in 1806–1808. Profits drawn on the company by its partners over the 35-year period from 1802 amounted to £360,000, equivalent to perhaps £30 million today (Wedderburn, pp. 443-444).

The Blackburns

We have already met Andrew Blackburn but not his brother Peter, nor Peter's son, John Blackburn (1756–1840) of Killearn. John was a 'Glasgow sugar merchant, who was a wealthy man having made his fortune in Jamaica' (MacTutor). He owned two estates, New Works and Wallen's, worked by 607 slaves (Almanac, 1826). Having returned home, he became a founder member of the fervently pro-slavery Glasgow West India Association in 1807 and resided on Queen Street in Edinburgh. Stephen Mullen comments (p. 274) that,

> John Blackburn was a prominent example of a West India supplier of credit to the elites. On his death in 1840, landed elites, including by the Duke of Hamilton and two sons of Baron MacDonald of the island of Skye, owed interest-bearing debts of over £30,000.

We have already seen how the Wedderburns were involved in two facets of the sugar, rum and slavery business – buying and owning land and slaves to produce sugar products in Jamaica itself and managing the business infrastructure from London, but here we see a third aspect, that of supplying credit for others so engaged.

The Blackburns were not part of the Wedderburn dynasty but they were to be bonded through marriage for two sons of John Blackburn married Wedderburn sisters. Peter Blackburn (1811–1870) married Jean Wedderburn and served as MP for Stirling 1855–1865. The Glasgow mathematician, Hugh Blackburn (1823–1909), married Jean's sister, Jemima (1823–1909), an artist of some significant note. Jean and Jemima were daughters of James Wedderburn Colvile (1782–1822), the fourth son of Dr James Wedderburn and Isabella (née Blackburn), and Aunt Isabella. James Wedderburn Colvile was a lawyer, judge and finally Solicitor General for Scotland whose wife was James Clerk Maxwell's Aunt Isabella (née Clerk).

Discussion

The Wedderburn family and its London business house formed a hugely successful empire. Their enormous wealth was accumulated through sound acumen in relation to the production and export of Jamaican sugar, molasses and rum to meet the clamour for these attractively-sweet products in Europe. But the production of sugar from cane is a labour-intensive industry, and although white indentured workers could initially meet the owners' needs, the expansion of the business led to an additional workforce of black African slaves, press-ganged on an enormous scale. The Wedderburns owned or managed numerous sugar plantations and to a greater or lesser extent, as on other estates, they would have treated their male slaves with cruelty and demanded favours of their female slaves. Many of those who prospered returned home to marry white women from 'good families', build fine houses and live well. It was a pattern exemplified by Dr James Wedderburn, as depicted in panel JM03 – Rosanna and Esther "keeping house", though not without repeatedly falling pregnant, Isabella Blackburn back in Scotland awaiting his return to respectable society.

James Wedderburn, Studio of Henry Raeburn (c.1820), Sotheby's, Public domain

Many Scottish estate owners and administrators became pillars of society, endowing schools and churches and financing new industries and infrastructure. Aunt Isabella's husband, James Wedderburn Colvile, was indeed a pillar of Scottish society, and while he was not directly involved in slavery, his inheritance was founded on it.

Arrival at 'Old 31' (18 November 1841), sketch by Jemima Wedderburn in the collection of the James Clerk Maxwell Foundation

And while the income from Uncle James's very successful legal career allowed James Clerk Maxwell to live in comfortable circumstances in Aunt Isabella's house in Heriot Row, the Wedderburn family wealth possibly added another level of comfort.

Sources and notes

1. The most detailed source of information about James Clerk Maxwell's extended family is John Arthur's book, *Brilliant Lives*. It contains diagrams for eight branches of the family tree, but the Wedderburn branch is not one

of them. That is not to say that the Wedderburns and their association with slavery are not covered. Indeed, there is a fair of amount detail on pages 167-173. Towards the end of the nineteenth century the family genealogist and historian, Alexander Dundas Ogilvy Wedderburn provided a most detailed account of an enormous number of members of the Wedderburn family and their financial affairs.

2. My starting point for this article was David Olusoga's book, *Black and British*, which gives a necessarily troubling overview of the slave trade and the workings of slave plantations. The research of Tom Devine and others casts light on particular aspects and provides detail.
3. For details of individual sugar estates, their owners and administrators, their slaves and the compensation claims made upon abolition, see the Legacies of British Slavery Database, housed at UCL.
4. This is the first part of an essay on the Wedderburns and slavery. The second part will cover the campaign to abolish slavery and those who railed against that campaign, the pragmatic package put in place by the British parliament to compensate estate owners for the loss of their property (land and slaves), and the measures taken by estate owners to keep their sugar production alive in a changing world. It will feature the story of Robert Wedderburn (depicted in panel JM03 above) but primarily follow the life of a leading actor in this drama, Andrew Wedderburn Colvile, Maxwell's Uncle Andrew.

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BOOK REVIEW: JAMES CLERK MAXWELL, ENGINEER?

The Geometry of Equilibrium: James Clerk Maxwell and 21st-Century Structural Mechanics, ed. William F. Baker & Allan McRobie (Cambridge University Press, 2025)

In 1861-62, Maxwell employed his cousin William Dyce Cay to build a bridge on the Glenlair estate. Cay, a mathematically gifted civil engineer, recalled that

> on one occasion, Maxwell spent the whole time during a walk of several miles over the hill from Glenlair to Parton, "giving one example after another to explain by illustration the principle of virtual velocities... The feeling I had," says Mr. Cay, "was that before I got to the bottom of one example he had rushed off to another." [1]

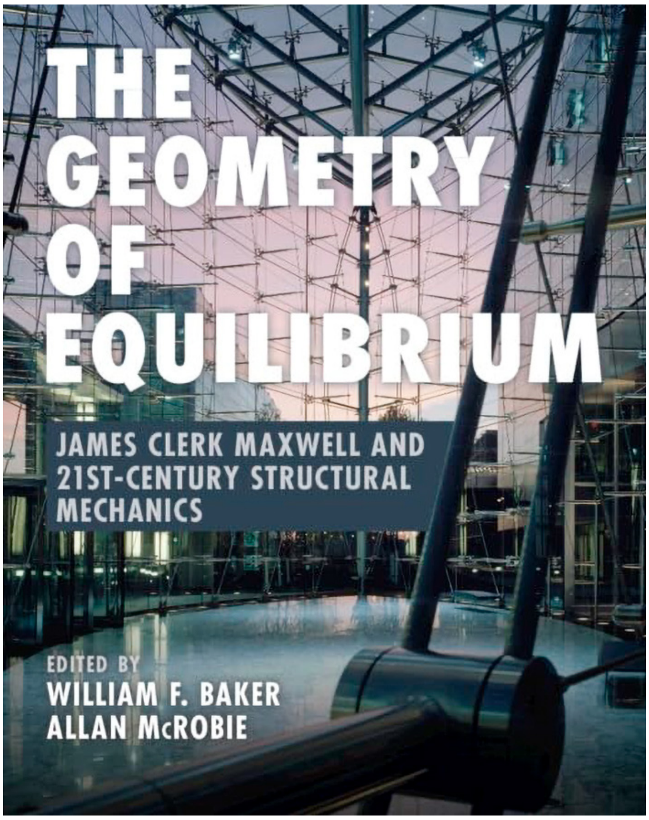
The incident is emblematic of the friendly, but not always comprehending, relationship between theoretical and practical mechanics in Maxwell's day. With that relationship in mind it may be surprising to encounter a book about Maxwell's contributions to structural engineering.

That contribution starts with Maxwell's contemporary, the inventive but erratic William John MacQuorn Rankine, who as an early academic civil engineer worked towards an elusive "harmony of theory and practice" [2]. In his *Manual of Applied Mechanics* (1858) Rankine attempted to systematise the burgeoning field of engineering mechanics in a manner that would be both mathematically rigorous and practically useful.

Rankine's *Manual* included several propositions concerning frames (more commonly known today as trusses): two-dimensional arrangements of rigid bars meeting at joints. One crucial question about such a frame is whether it is rigid: can the geometry be changed without altering the length of any bar? A related question is what compressional or tensional forces result when an external load is applied at a joint, and whether the answer can be determined solely from the geometry of the frame.

Today these would usually be treated as problems in elasticity, to be tackled by formulating and solving appropriate sets of differential equations. Rankine's approach was geometrical: given a diagram representing the joints and bars, to construct a corresponding diagram representing the forces in each bar. The line representing the force in each bar must be parallel to the bar and proportional in length to the magnitude of the force, and if the frame is in equilibrium, then the forces acting at each joint must form a closed polygon. It was an elegant idea but one of several that Rankine left, as a reviewer complained, "to the reader's own ingenuity" [3].

Maxwell was among the readers whose ingenuity was piqued. In a series of publications between 1864 and 1876, he elaborated Rankine's theory of "reciprocal diagrams" and extended it further. A natural extension was to three dimensions, in which forces are represented by polygonal faces which must form closed polyhedra at each joint. Interrogating the conditions under which reciprocal



diagrams could be drawn provided graph-theoretical counting rules to determine the conditions under which a frame could be rigid, and revealed a projective relationship between two-dimensional reciprocal diagrams and polyhedra.

Reinterpreting reciprocal diagrams in terms of coordinates connected geometry to analysis, and allowed the polyhedra corresponding to these diagrams to be reinterpreted as stress functions – scalar functions of position from which the stress tensor can be obtained – thus embedding Rankine's idealised frames within the theory of continuum mechanics. Maxwell also deployed the modern concept of energy to prove general results: the "reciprocal theorem" which relates displacements and forces in a framework, and the "load-path theorem" which relates the sums of the compressional and tensional forces in a loaded frame.

The methods of graphical statics which Maxwell helped develop were in use by practising engineers for several decades before dropping out of fashion. (As early as 1891, a Nature reviewer commented that "although nowadays indispensable for engineering purposes, the subject does not flourish in our theoretical courses of instruction" [4].) *The project of The Geometry of Equilibrium* is to bring them back.

As the authors acknowledge, this is not an easy task. Maxwell's own presentation is sometimes gnomic and often at odds with modern terminology or notation, and it assumes fluency with a geometrical toolkit that few engineers or mathematicians now possess. Their solution is an edited volume in three parts, which are not intended to be read in sequence.

Part I, "Maxwell and Structural Mechanics", explores ways in which Maxwell's ideas remain useful to modern structural engineering, architecture, and materials science. Part II, "Concepts from Maxwell's Articles", unpacks these ideas and translates them into modern terms. Part III reprints seven of Maxwell's original articles with lightly edited text, redrawn figures, and copious annotations. Different readers will presumably choose their own paths through the book; one useful path begins by reading chapters 1 and 2, which introduce the key concepts, skipping to chapter 7 for a primer on plane reciprocal diagrams, and then reading Maxwell's original paper from 1864.

Bringing Maxwell's geometrical statics back into vogue might seem somewhat quixotic, but the authors are not mere dreamers: William Baker in particular is best known as the chief structural engineer on the Burj Khalifa and other supertall buildings. Unlike their Victorian counterparts, they see geometrical methods less as a means of computation than as a creative tool, giving them access to "new discoveries and designs that might otherwise be unattainable" [5]. Those of us who are unlikely to find ourselves designing skyscrapers or metamaterials may still find it satisfying to glimpse some of the geometrical elegance that underlies structural complexity.

Maxwell's powerful ideas, as Cay discovered, take time to grasp. Especially in Part II, the authors do sterling work to make them more accessible; their efforts to provide a uniform convention for drawing reciprocal figures are particularly welcome. Nevertheless, this is a book that needs to be read repeatedly, perhaps taking a different path through the material every time [6]. It might come into its own most fully as the basis of a reading class or a seminar series, allowing participants to argue their way into a modern understanding of Maxwell in much the same way that the authors themselves did. It deserves to find such a role, and I hope that when it does the seminars will attract both engineers and mathematicians, willing to walk together in their search for insight.

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[2] Ben Marsden, "Ranking Rankine: W. J. M. Rankine (1820-72) and the making of 'engineering science' revisited", History of Science 51 (2013), 434-456.

[3] Mechanics Magazine, 8 April 1859, p. 234.

[4] Nature 1132(44), 9 July 1891, p. 221.

[5] William Baker & John Ochsendorf, The Geometry of Equilibrium, p. 8.

[6] A minor gripe is that a more comprehensive index would have made it easier to track concepts across the chapters.

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VISITING MAXWELL'S BIRTHPLACE IN INDIA STREET

The Foundation maintains a small museum at Maxwell's birthplace in India Street, Edinburgh, with displays and exhibits telling the story of James's life, and illustrating his many scientific achievements. In 2025 around 800 people visited the museum as individuals, in groups, or during the annual Edinburgh Doors Open event. Guided tours are given by a small team of volunteers, and can be arranged by supplying details, including the size of the group and the preferred date; see **https://clerkmaxwellfoundation.org/html/visit_booking.html**.

The photograph shows visitors on 13 June 2026, Maxwell's 195th birthday, and was taken in the room where James was most probably born. The young Maxwell and his mother Frances appear in the portrait behind the group. A cake was shared with the group to mark the occasion.

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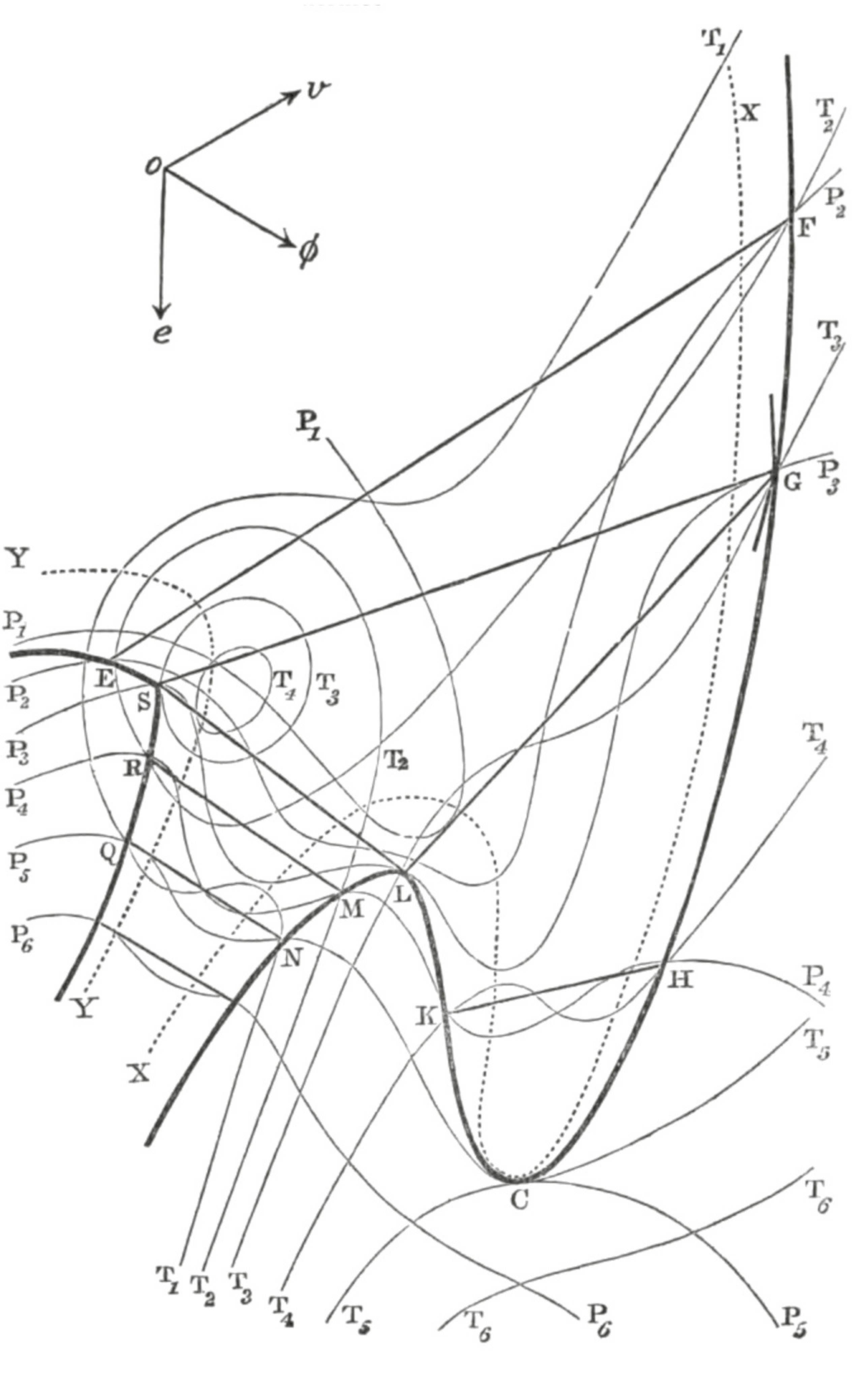

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