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THE AWARDING OF THE COPLEY MEDAL AND THE 'DISCOVERY' OF THE LAW OF CONSERVATION OF ENERGY: JOULE, MAYER AND HELMHOLTZ REVISITED

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This article analyses the awarding of the Royal Society's Copley Medal to James Prescott Joule (1870), Julius Robert Mayer (1871) and Hermann Helmholtz (1873) in the wake of the establishment of the law of conservation of energy during the 1850s and 1860s. It seeks to reconstruct the context in which the awards occurred, emphasizing at once a combination of individual scientific achievement, advocacy on behalf of Joule's supporters, nationalism, and the special role that Helmholtz played thanks to the strong social relationship that he had developed with the British scientific elite in the two decades before receiving his award, the last of the three. The award in turn strengthened that relationship, as the great subject of discussion in physics now gradually turned from thermodynamics to electromagnetism and to reaching practical agreements in electrical metrology between the British, the Germans and others.

Keywords: Copley Medal; energy conservation; Joule; Mayer; Helmholtz; nineteenth-century science; history of physics; history of scientific institutions

INTRODUCTION

In the early 1870s, James Prescott Joule, Julius Robert Mayer and Hermann Helmholtz each won the Royal Society of London's highly coveted Copley Medal. The medal was (and is) arguably Britain's most distinguished scientific award, and even with the coming of the Nobel prizes in 1901 is also arguably one of the world's premier scientific awards. This article addresses the issue of why these three men of science won the award and won it when they did, looking in particular at their advocates and at Helmholtz's long-standing personal relationship with various British men of science and British scientific institutions.[1] The advocacy (and disputing) was done by others, mostly John Tyndall, Peter Guthrie Tait and, to a smaller extent, William Thomson. In addition, the article seeks to show this, and

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how national pride and prejudice played a part—but only a part—in the decision making of these awards, and also to demonstrate the limitations of nationalism in conferring scientific honours because issues of scientific achievement, distribution of field, and personal relationships (at least in Helmholtz's case) also played their parts.

The controversy over the 'discovery' of the law of conservation of energy: Tyndall versus Thomson and Tait

Twenty years or so before their Copley Medals were awarded, between 1848 and 1851, Mayer and Joule had already had a priority dispute over the mechanical equivalent of heat. One result of this was that the Royal Society awarded Mayer its Royal Medal in 1852 for his work.[2] By the early 1860s, however, as the law of conservation of energy (as well as the second law of thermodynamics, that concerning entropy) had become an intellectually settled part of physics and as 'energy physics' became the language and viewpoint of all physicists (and other men of science)—and thus, as the entire subject had become of markedly increased importance to physics as a whole and to other fields—the issue of who had first 'discovered' the law of conservation of energy became of increasing interest and dispute. Tyndall became a key figure in renewing such interest when he held a series of lectures on heat from the mechanical point of view. But before publishing these lectures, Tyndall wanted Helmholtz's and Rudolf Clausius's assessments as to 'what Mayer has really done. Did he attempt to determine the mechanical equivalent of heat; or was Joule the first?'[3] This inquiry, and a lecture entitled 'On Force' (1862), effectively pitted Tyndall against Thomson and Tait in a dispute that became personal as well as historical.[4]

Hence Tyndall's attempt to win Helmholtz, whose general outlook was not so different from his own, and Clausius to his side. Helmholtz told Tyndall that it was well known that Mayer suffered from '*Geisteskrankheit*'—in 1850 he had jumped out of a third-story window, and on several occasions he had stayed at a sanatorium or was confined to an asylum. Still, Helmholtz further explained, Mayer had indeed calculated the mechanical equivalent of heat, although not in a way that avoided certain objections. (Helmholtz himself had several times and in public addresses declared Mayer's and Joule's priority over his own essay on the conservation of force (1847), although, to be sure, he also said that at that time he was unaware of Mayer's work and he noted that others had made contributions as well. Mayer himself agreed that he and Helmholtz, as well as Joule, had worked independently of one another.)[5] Helmholtz commended Tyndall for wanting to provide a popular account of the mechanical theory of heat, which he thought was needed and which Tyndall could do in his '*meisterhaft*' way.[6] That (along with Clausius's testament) gave Tyndall sufficient writ to become a public supporter of Mayer in Britain, which he did in his lecture 'On Force' at the Royal Institution in June 1862; he there presented Joule's and Thomson's works as secondary to Mayer's.[7] That talk put him at great odds with Joule and his most vociferous supporters, namely Thomson and Tait. The talk and its aftermath became a public controversy, one of the greatest of Tyndall's controversial career. Tyndall's support for Mayer lay perhaps less in his opposition to a priority claim on Joule's behalf than in his belief that Mayer deserved greater recognition; it certainly helped in the subsequent recognition of Mayer's work.[8] One outcome of the controversy was a reply later that year, in a popular but Christian journal, by Thomson

and Tait on the meaning of 'energy', including the coinage of a new term, 'kinetic energy'. Tyndall, in turn, sought to counter Thomson (alone) in the pages of *Philosophical Magazine*.[9]

Helmholtz stood in the middle of all this—both as a contributor to the development of the law of conservation of force/energy, as a popularizer of it, and as a friend of several of the disputants who hoped that he would support their respective views.[10] But if his relationship with Thomson was especially close, as it was in rather different ways with Henry Enfield Roscoe and Tyndall, his attitude towards Tait, Thomson's close collaborator and friend, was standoffish. Where Thomson and Tait thought little of Tyndall as a man of science and looked down on him for his popularizations, Helmholtz by contrast had great sympathy for and gave great support to Tyndall's popularizing efforts. He did not, however, want to offend either Thomson or Tyndall by taking sides with one against the other. More importantly, Tait was a terrible chauvinist. His prejudice in favour of his fellow British men of science (Balfour Stewart, George Gabriel Stokes, Joule, W. J. M. Rankine and James Clerk Maxwell) against their German counterparts (Mayer, Gustav Robert Kirchhoff and Clausius) at times put Helmholtz in a difficult position *vis-à-vis* his own countrymen.

All this emerged especially clearly in what became a second outcome of the controversy, a booklet by Tait entitled *Sketch of Thermodynamics* (1868). At Thomson's recommendation, in February 1867 Tait sent Helmholtz the first two draft chapters of his 'little work' on the history of thermodynamics. He said his purpose was to give Joule and Thomson greater credit than they had so far had for their contributions to the subject. However, he feared that in doing so Helmholtz (and Kirchhoff) might be offended, and so he asked Helmholtz (and thus his Heidelberg colleague Kirchhoff, too) to 'kindly point out to me anything which appears to you objectionable in the way in which I have spoken of your connexion with the subject, [and] I shall be delighted to correct it before my little work is published.' He wrote a similar letter to Clausius.[11] He told Helmholtz that he and Thomson thought Joule had priority over Mayer as concerned the discovery of conservation of energy, and he thought Tyndall had come out too strongly in favour of Mayer.[12] A year later Tait sent Helmholtz advance proofs of his *Sketch of Thermodynamics* that concerned the priority of Kirchhoff *vis-à-vis* Stewart in the matter of spectrum analysis. He wanted Helmholtz's approval of his historical analysis, and he feared Clausius's criticisms. He also asked Helmholtz for permission to quote him (from a letter of Helmholtz's) on Mayer in his preface.[13] Helmholtz agreed to allow the quotations, but on condition that he first be allowed to review Tait's text in proof, which more than satisfied Tait.[14]

In his preface Tait declared 'that it is almost impossible to be strictly impartial, however we may strive to be so', and that 'Joule's magnificent, but much neglected, papers of a quarter of a century ago are being rediscovered and attributed to others.' He conceded, however, that he may have taken 'a somewhat too British point of view'. For two full pages he quoted Helmholtz on Kirchhoff and, especially, Mayer. Helmholtz, however, did not share Tait's views on Mayer. Tait admitted that he agreed with 'a great part' of Helmholtz's evaluation of Mayer's contribution, and said that, were it still possible, he would have changed part of his published text. He added: 'I think it best to retain them, giving Mayer however the benefit of the able and weighty advocacy of Helmholtz.'[15] Tait also noted that his history of the conservation of energy was largely confined to assessing the contributions of Joule versus those of Mayer, while largely merely acknowledging that

of others (such as Ludvig Colding, Marc Séguin and Helmholtz). In the preface to a second edition of his *Sketch* (1877), Tait's dispute with Clausius and his advocacy of Thomson's priority in discovering the second law of thermodynamics came more to the fore.[16] As Tait concluded:

> Thus, in all the scientifically legitimate steps which the early history of the principle records, Joule had the priority. His work has been much extended by others, especially Clausius, Helmholtz, Mayer, Rankine, and Thomson, in the developed applications of the principle in many directions. . . . [T]he experimental foundation of the principle in its generality, and the earliest suggestions of many of its most important applications, belong unquestionably to Joule.

As for Helmholtz, he declared him to be 'one of the most successful of the early promoters of the science of energy on legitimate principles' and he thought his essay of 1847 'On the Conservation of Force' to be 'admirable'.[17] Thomson, for his part, wrote to Helmholtz: 'Joule did and published more for the establishment and extension of thermodynamics in his two or three papers published before Mayer came on the field than all that Mayer has done put together.'[18] Clausius thought that Tait's favouritism of Joule, Rankine and Thomson over himself and Mayer showed that 'he wrote the book not as an impartial judge but rather as an advocate who has set himself the task of saying as much as possible in favour of his clients.'[19]

Awarding the Copley Medal to Joule and Mayer

The third and final outcome of the new interest in assessing who had 'discovered' the law of conservation of energy concerned the awarding of the Royal Society's Copley Medal for doing so (or, more broadly, for the study of heat). The first indications of this came in 1869, when William Robert Grove, Victor Regnault and August Wilhelm von Hofmann were nominated for the award. Regnault, a Frenchman, won, with the Council noting in particular his experimental work (including that on the specific heats of gases and vapours), that led to (unspecified) laws and data needed for making physical calculations concerning steam engines.[20] That suggests the importance that the Society (or at least its Council) placed on precise, empirical work. Then, in 1870, Joule, Helmholtz and Charles Eugène Delaunay, the French astronomer and mathematician, were nominated for the Copley Medal. It was Tyndall, perhaps rather surprisingly, who formally nominated Joule, which he did 'for his experimental researches on the Dynamical Theory of Heat', and for which he won the award.[21] Indeed, Edward Sabine, the President of the Society, explicitly noted that Joule was awarded the Copley Medal for precisely the same researches—his 'great principle'—for which he had been awarded the Royal Medal in 1852; it was 'exceedingly rare', he added self-consciously, for the Society to award two medals for the same researches.[22] No explanation was offered, but it may be supposed that the reason the Society did so was to re-emphasize Joule's (and Britain's) priority in what had now become a subject (energy conservation) of major importance to all of science. Like Tait in his recent *Sketch of Thermodynamics*, the Society may have wished to reaffirm its support for Joule, a British man of science.

However that may have been, now that Joule had won the Copley Medal, that ironically eased the situation for a possible award to Mayer or Helmholtz, who, along with Delaunay, Grove, Claude Bernard and Emil du Bois-Reymond, were all nominated for the Copley

Medal for 1871. It was (unsurprisingly) Tyndall who nominated Mayer, which he did 'for his researches on the Mechanics of Heat; including Essays on:– 1. The Forces of Inorganic Nature. 2. Organic Motion in connexion with Nutrition. 3. Fever. 4. Celestial Dynamics. 5. The Mechanical Equivalent of Heat.' Such a broad listing of work more or less closely related to the subject of heat helped differentiate Mayer from Joule. Helmholtz, in contrast, was nominated by Michael Foster, the physiologist, 'for his Memoir on the Conservation of Force, and his works on Physiological Optics and the Physiological Theory of Music', which was an even broader listing, and Grove was again nominated 'for his Work on the Correlation of the Physical Forces, and his various researches in Electricity'. Mayer won the award.[23] He did so, President George Biddell Airy said, principally but not solely for his work on the mechanical equivalent of heat. Furthermore, in the light of the previous year's award to Joule, this

> require[d] some explanation on the part of the President and Council, inasmuch as this is the second of two Copley Medals awarded (and, I believe, in each case rightly awarded) for what may, perhaps, be mainly regarded as one and the same discovery,—the later (which is the present award to Dr. Mayer) being for investigations earlier in date than those of our countryman Mr. Joule, to whom the first Medal of the two was awarded. This seeming inconsistency can, I believe, be fully justified.

To do so, Airy had asked Stokes, the Lucasian Professor of Mathematics and a leading mathematical physicist, for his expert opinion. The latter reported that, as shown in Mayer's paper of 1842,

> Mayer obtained a numerical value of the mechanical equivalent of heat which, when corrected by employing a more precise value of the specific heat of air than that accessible to Mayer, does not much differ from Joule's result. This was undoubtedly a bold idea, and the numerical value obtained by Mayer's method is, as we now know, very nearly correct. Nevertheless it must be observed that an essential condition in a trustworthy determination is wanting in Mayer's method; *the portion of matter operated on does not go through a cycle of changes*. . . . Hence the practical correctness of the equivalent obtained by Mayer's method must not lead us to shut our eyes to the merit of our own countryman Joule, in being the first to determine the mechanical equivalent of heat by methods which are unexceptionable, as fulfilling the essential condition that no ultimate change of state is produced in the matter operated upon.[24]

In short, Mayer got the 'correct' answer first, but by a slightly faulty physical argument, which effectively justified, at least in the eyes of the Society's Council, both Joule's and Mayer's receiving the Copley Medal. Both Airy and Stokes, it may be noted, made reference to 'our own countryman Joule'.

Helmholtz and the British elite, *circa* 1870

But what, then, about Helmholtz and his essay of 1847? Did he not deserve something here for his generalization in the form of the law of conservation of force? Certainly in terms of public recognition, these were banner years for Helmholtz in general and for his relations with the British scientific elite in particular, and to understand his receiving the Copley Medal, after Joule and Mayer had won theirs for determining the mechanical equivalent of heat, also requires an appreciation of his continued high standing among that elite. The British Medical Association, for example, asked him to attend its meeting at Oxford in

August 1868, for which they would assume his room and board.[25] Henry Wentworth Acland, the Regius Professor of Medicine at Oxford University, also wanted to know whether Helmholtz intended to be at Oxford, as he hoped to see him there. Friedrich Max Müller, the comparative philologist and orientalist, would welcome him too, as would others. If he came, Acland wanted him to demonstrate his ophthalmometer and an acoustic device. 'Our medical friends would be grateful for a demonstration of either.'[26] Similarly, the British Association for the Advancement of Science (BAAS), always keen to get foreigners to attend, invited him to come to its meeting at Norwich that August and to give a paper.[27] Helmholtz did not go to Britain in 1868, but these invitations suggest his continued high standing in the eyes of Britain's scientific leadership.[28]

Nine months later, Acland wrote to Helmholtz again to say that he and others at Oxford—including Robert Bellamy Clifton (Professor of Experimental Philosophy (that is, physics)), William Donkin (Savilian Professor of Astronomy) and Henry J. S. Smith (Savilian Professor of Geometry)—'are very anxious both to see and to *hear* you here.' They hoped this would occur in the summer of 1870, when Clifton's new physics laboratory, the Clarendon, would be nearly finished. If, in the meantime, Helmholtz would be coming to England that autumn, Acland hoped to see him then, too. ('I need not say how many houses would compete to receive you.') He also wanted Helmholtz to give several lectures in Oxford on physics and medicine, which Oxford University Press would then publish. 'We are in a transition state—which is at once interesting, anxious & laborious.' Finally, he wanted to know whether Helmholtz would be going to the BAAS meeting in Exeter that coming summer.[29]

Furthermore, Helmholtz was invited (through Acland) by Lord Robert Cecil, Third Marquess of Salisbury and Oxford's newly elected Chancellor, to come and accept an honorary Doctor of Laws degree at Salisbury's installation ceremony. Lord Salisbury, who had taken a (fourth-class) degree in mathematics, was himself an amateur man of science and one who supported the natural sciences at Oxford while criticizing an overly great concern with classical education. (Later, too, he would enthusiastically advocate for the installation of electrical lighting systems in Britain.) Like Salisbury, Acland was a leading modernizer at Oxford. He asked Helmholtz to allow his name to be put forward for the degree—Darwin, Tyndall and Huxley were also being nominated—and whether he could come to the inauguration (21 and 22 June 1870). In the event, only Helmholtz's nomination was successful. Helmholtz was uncertain whether his schedule would permit him to go to Oxford, but he felt honoured.[30] Salisbury then wrote directly, inviting him to visit Oxford 'in order to receive an honorary degree'. He continued, 'The honour of your presence will be greatly felt by the University, as well as by myself its Chancellor: & your acceptance of an honorary degree will do much to stimulate the attention which is now happily being given to [the] natural sciences at that place.'[31] Helmholtz did not go to Oxford that June, no doubt because he was in the midst both of teaching in Heidelberg and of negotiating for a new position in Berlin (see below).

Elsewhere in Europe, moreover, the Paris Académie des sciences in late December 1869 placed Helmholtz's name at the head of a list of 15 physicists—including A. J. Ångström, Heinrich Dove, Grove, Joseph Henry, Joule, Kirchhoff, Mayer, Stokes, Thomson and Tyndall—nominated to fill a recent vacancy for corresponding member in its Section de Physique.[32] Helmholtz received 37 (of 44) votes, far outdistancing even his closest competitors. In early January 1870, he was made a corresponding member of the section for *physique générale*.[33] The French scientific elite clearly had, like its British

counterpart, a high opinion of Helmholtz and his work, and apparently a higher one of him than of Joule, Mayer and the other nominees.

The Paris Académie had doubtless not admitted him sooner because it faced a problem that some other academies also faced: there had to be a vacancy before there could be a nomination for a new member. At the Berlin Academy of Sciences, where Helmholtz had been a corresponding member since 1857, he could not became a 'foreign' member until such a position first opened up, which it did in 1870. In that year he first received a unanimous vote from the Physical–Mathematical Class, and then the full Academy (the Plenum) voted in his favour, with his election becoming official on 1 June 1870.[34]

Similarly and almost simultaneously, the University of Berlin sought a successor for Gustav Magnus, its Professor of Physics, who died in April 1870. Only two names came under consideration—Kirchhoff and Helmholtz—and, after the former declined in June of the same year, Helmholtz became the only possibility. After delays due to the onset of the Franco-Prussian War, in October 1870 Berlin opened negotiations with Helmholtz. He was made an offer that December, and as the year closed he offered his resignation to Baden (Heidelberg) and his acceptance to Prussia (Berlin).

Berlin was not the only university then interested in Helmholtz as its professor of physics. For one, Vienna also wanted him.[35] More pertinently, no sooner had Helmholtz signed up with Berlin than an (informal) offer from Cambridge arrived. Britain was in the early stages of its Endowment of Scientific Research movement, which sought especially to increase support for pure scientific research. Since its earliest beginnings in the 1850s, this renewed British emphasis on research had looked above all to Germany as its standard.[36] Helmholtz, with his excellent relations with many British men of science, was just what some in Britain thought was needed. In late January, Thomson, who knew of Helmholtz's offer from Berlin, wrote to him on behalf of Stokes and others at Cambridge to ask whether he might consider accepting the new professorship of experimental physics and the directorship of its equally new Cavendish Laboratory. 'It is much desired to create in Cambridge a school of experimental science,' Thomson wrote, 'not merely by a system of lectures with experimental illustrations, but by a physical laboratory in which students under direction of the professor and his assistant or assistants, would perform experiments, and the professor would have all facilities attainable, for making experimental investigations.' The new laboratory building was under construction (the Duke of Devonshire had given £6000 for it). Helmholtz could expect an annual compensation of £500 along with student fees. In addition, he would be appointed a fellow of Peterhouse College, which meant additional income (£250–300). All told, his income would be at least £800 annually, Thomson thought. If he also received a fellowship to Trinity, he would get an additional £600, making a total of about £1400 per year. Thomson said that, apart from the financial inducement, Britain offered other advantages: 'the desire for physical science is growing stronger and stronger in the University, and the force of public opinion is steadily advancing in support of it, and to stimulate it when stimulus is needed.' Helmholtz would have to lecture only 20 weeks per year, leaving him the remaining time for his own research.

> I need not say that it would be a great gratification and advantage to English scientific men to have you among us instead of merely having very rare opportunities of seeing you, and that I myself would consider the difference of distances from Glasgow to Cambridge and Berlin a great gain.[37]

However, Helmholtz declined the offer—in March 1871 Maxwell accepted the Cavendish professorship—but he sent a copy of Thomson's letter to the ministry of culture in Berlin, which said that it was of course pleased that he had declined.[38] The ministry was clearly nervous, and was no doubt relieved when Helmholtz began teaching there on 1 April 1871. He now automatically became an 'ordinary' member of the Academy, and one of his first acts was to nominate (in June 1871) his friend Thomson as a corresponding member.[39]

By August 1871, after his first semester in Berlin, Helmholtz needed rest and relaxation. That past March, Thomson, the president-elect of the BAAS, had invited him to attend the society's meeting in Edinburgh in early August and afterwards to enjoy a cruise on his new schooner-yacht, the *Lalla Rookh*, for several weeks sailing in the West Highlands and the Hebrides. He also invited Maxwell, Huxley, Tyndall and Tait.[40] To sweeten the pot, John Hughes Bennett, the British physiologist and pathologist, invited Helmholtz to stay in his Edinburgh residence during the meeting; the chemist Alexander Crum Brown, Tait's brother-in-law, also invited Helmholtz to stay with him in his Edinburgh home (where Rankine would also be a guest), just as Crum Brown had stayed with Helmholtz in Heidelberg.[41] In June, Thomson again urged Helmholtz to visit Scotland, while also thanking him for the announcement of his daughter's (Käthe's) wedding.[42] Helmholtz decided not to go to the BAAS meeting but he did want to go sailing with Thomson, who was delighted and who noted that perhaps Helmholtz could 'mix a little work' in with the cruise.[43] All this irritated Tait, who feared he would again fail to meet Helmholtz and who hoped to teach Helmholtz 'the mysteries of golf'.[44] It was Helmholtz's fifth visit to Britain, and his first since 1864.

In early August, Helmholtz and his family went to the seashore, near Kiel,[45] but in mid-month he left them for Thomson and Scotland.[46] He found the Edinburgh hillsides and St Andrews Bay most impressive, and the people there elegant. He dined with Tait (who played a good deal of golf and who would accompany him to Thomson's), with the Belfast chemist Thomas Andrews and with Huxley, all 'noisy, pleasant, and interesting people'. Andrews showed them several noteworthy experiments. Tait was as enamoured of golf as Thomson was of sailing. He got Helmholtz to try a round; the results were as might be expected.[47]

On 24 August, Helmholtz joined Thomson in Glasgow.[48] He was quite impressed with both the new University of Glasgow and with the Duke of Argyle's estate.[49] Then they went sailing on the *Lalla Rookh*.[50] On board ship with Thomson and Helmholtz were, at various times, Thomson's brother James, Crum Brown, and others (but not the other original invitees Maxwell, Huxley, Tyndall and Tait).[51] While sailing between Scotland and Ireland, Helmholtz and Thomson discussed the theory of waves, 'which he [Thomson] also most prefers to treat as a sort of "race" between the two of us.'[52] Thomson's competitiveness astounded Helmholtz. When Thomson went ashore by himself at Inveraray, he supposedly warned Helmholtz before departing: 'Now, mind, Helmholtz, you're not to work at waves while I'm away.'[53]

In Belfast, they visited Andrews and his laboratory, saw a regatta, and dined at James Thomson's, who was Professor of Engineering there. They were all, Helmholtz said, 'sharp people'. Northern Ireland, he noted, was ruled by the Orangemen (a Protestant Irish order), who 'if possible are even more Prussian than the Prussians themselves'. They hoped that Prussia would establish a new empire, like that of Charlemagne, 'in order to keep the Celts and Slavs down and to save civilization'. The Scots, he found, spoke even

more harshly of the French than the Germans did: they considered them 'like savages whose civilization has been completely lost'.[54] They spent a day in Oban, on the west coast of Scotland, at the country house of a high-ranking British diplomat and politician, Lord Dufferin (Frederick Temple Hamilton-Temple-Blackwood), who insisted that Thomson and Helmholtz stay overnight with him. On Sunday, Helmholtz was forced to attend Anglican services in Dufferin's personal chapel.[55] They hurried to the countryside estate of Hugh and Jemima Blackburn in Roshven, which was surrounded by 'the loneliest mountains'. Blackburn was Thomson's closest friend and was Professor of Mathematics at Glasgow, where he had succeeded to the chair previously held by Thomson's father. Thomson was so at home there, Helmholtz said, 'that he always carries around with him his mathematical notebook, and as soon as something occurs to him, right there, in the middle of a group of people, he begins to calculate, which people here generally regard with a certain awe. How would it be', he asked sarcastically, 'if I too got the Berliners used to such a thing!'[56] In the Sound of Mull, while on board the *Lalla Rookh*, Helmholtz and Thomson conducted experiments—they hung a fishing line a few feet into the water—to determine the minimum velocity of wave propagation of ripples on the water's surface, a topic on which Thomson had been working for some time and on which he would eventually publish. While they were experimenting, small whales approached their ship closely, which gave them something (else) to talk about.[57] Despite all the pleasures of sailing, of partying, of sightseeing, and even of experimenting and talking science with Thomson, Helmholtz had had enough. When they reached Glasgow in a few days, he would leave Thomson and head home.[58]

The cruise and the trip in general proved of great benefit to Helmholtz. He met lots of British men of science, including the chemists John Ferguson (soon to become Regius Professor of Chemistry at the University of Glasgow), John Millar Thomson and Lord Rayleigh, as well as other members of the Strutt family.[59] The cruise had also benefited his health: 'I began my lectures a week ago', he wrote to Thomson in early November, 'and I find myself much more comfortable at present, than during the summer. I have time, to work for myself.'[60]

Helmholtz gets the Copley Medal

With all these connections to the British elite, and with Joule and Mayer now having received Copley Medals for their work on the mechanical equivalent of heat, it might be thought that Helmholtz would now receive one, too. But his nomination fared no better in 1872, when he was nominated (by Clifton, and this time solely and broadly 'for his researches on Physics and Physiology)', along with Bernard, Delaunay, Hofmann, Joseph Liouville, Friedrich Wöhler and Karl Adolph Wurtz; the award went instead to Wöhler for his work in chemistry.[61] Perhaps this helps explain—as a sort of compensation?—why, in late 1872, Thomson suggested to the Master of Peterhouse and the Vice-Chancellor of the University of Cambridge that Helmholtz be invited to give the annual Rede Lecture there for 1873. They agreed—'the authorities are always anxious to have a man of high distinction', he told Helmholtz—and Thomson invited Helmholtz on their behalf. Thomson was keen to get him to accept and to come to Cambridge.[62] But Helmholtz declined. He was simply too preoccupied with work in Berlin; besides, he doubted that he could speak English sufficiently well in such an academic format.[63] The authorities now had to find someone else, and that choice fell on none other than Tait.[64]

Then, in the spring of 1873, Helmholtz was again nominated for the Copley Medal (by Clifton, and this time seconded by Stokes), but on this occasion 'for his researches in Physics and Physiology' (that is, without any particular reference to his essay of 1847 or to any other particular works by him) and with Hofmann as his only competitor.[65] In September, Tyndall told Helmholtz privately that he hoped 'that the Council of the Royal Society will add its unanimous verdict this year to that of the advisers of the King of Prussia', who had recently given him an award.[66] (Tyndall presumably meant Helmholtz's election on 17 August of that year to Prussia's *Orden pour le mérite für Wissenschaften und Künste*, its most prestigious civil order for the arts, letters and sciences.)[67] In early November, two days before Helmholtz received official notice from the Society, Tyndall sent him a cryptic telegram saying that 'If you will come over I will make up Faradays own bed for you.' Helmholtz could not understand the message until after he received the Society's official communication, which said, in part, that he was to receive the medal 'for your researches in Physics and Physiology'.[68] A few days later Tyndall wrote again to say, this time explicitly, that Helmholtz had won the medal and that he hoped that Helmholtz could come to London for the actual awarding by the Foreign Secretary and for the dinner of the Fellows that followed.[69] Helmholtz told Tyndall that he was greatly honoured to receive the Copley Medal, but that there could be no question of his travelling to London merely to receive it personally and to express his gratitude. He explained that even if he could manage to free his work schedule for four or five days to make the trip, the combination of a rapid trip and the festivities in London would be more than his health might allow. He wrote a separate letter to the Society that, he knew, would be read aloud at the banquet. In the meantime, he was working on a short preface to the second part of the German translation of Thomson and Tait's *Treatise on Natural Philosophy*.[70] A week or so later, the President, Joseph Dalton Hooker, in formally making the award to Helmholtz, declared before the Society:

> It would be difficult for me, within the limits of this Address, to state the number and the importance of the claims of Professor Helmholtz to our recognition. His published books on the Conservation of Energy and the Theory of Music, and his 'Handbook on Physiological Optics,' have assisted greatly in the progress of their respective sciences. His memoirs have ranged through nervous physiology, hydrodynamical theory, instruments (as the ophthalmometer and the ophthalmoscope) for exact measurement and for medical examination of the eye, and other important subjects, and have been generally recognized as giving real additions to our knowledge.[71]

There could be no question of giving yet another Copley Medal solely for work that led to the law of conservation of energy; instead, Helmholtz got it for the totality of his scientific researches. Moreover, it may be presumed, the British scientific elite was in effect recognizing the long-standing and highly valued relationship that many members of British scientific life had developed with him—and he with them. The Copley Medal put a(nother) seal of approval on that relationship.

Nor was that quite all in the way of British honours and Helmholtz's involvement with the British scientific elite at that time. At virtually the same moment that he received the Copley Medal, he was also elected an Honorary Fellow of the Royal Medical and Chirurgical Society of London.[72] Six months later he was again invited to England to receive an award, this time from Cambridge University, and he again regretted that he could not go. He explained that neither his current teaching duties nor those as the Dean of the Philosophical Faculty at

Berlin, 'which makes me responsible for a great amount of business not easily to be transferred upon anybody else', permitted him to leave Berlin for any length of time during the semester. He added that just last December he had been invited to London to receive the Copley Medal and that, for the same reasons, he was 'detained' from doing so.[73]

The awarding of the Copley Medal to Helmholtz was anything but the end of his relationship with British science. Since the late 1860s that relationship had begun increasingly to revolve around a new 'hot' issue in physics and technology, that concerning Maxwell's version of electromagnetic theory and the closely related matter of electrical standards. The 'bridge' to British science that Helmholtz had built in the first half of his career would also have important uses in the second half, as now not only thermodynamics but also electromagnetic theory would yield enormous consequences for both German (and British) physics and economic life during the coming decades, and indeed for physics and economies around the globe. But that is another story.

Acknowledgements

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Notes

1 For background and an extensive discussion of this point, see David Cahan, 'Helmholtz and the British scientific elite: from force conservation to energy conservation', *Notes Rec. R. Soc.* **66**, 55–68 (2012). (doi:10.1098/rsnr.2011.0044)

2 J. T. Lloyd, 'Background to the Joule–Mayer controversy', *Notes Rec. R. Soc. Lond.* **25**, 211–225 (1970); Kenneth Caneva, *Robert Mayer and the conservation of energy* (Princeton University Press, 1993), pp. 38 and 262; *Record of the Royal Society of London for the Promotion of Natural Knowledge*, 4th edn (Morrison & Gibb, London, 1940), p. 350.

3 John Tyndall to Hermann Helmholtz, 5 May 1862 (quotation), Nachlaß Hermann von Helmholtz, Nr. 477, Berlin-Brandenburgische Akademie der Wissenschaften, Akademiearchiv, Berlin (hereafter abbreviated as HN); Rudolph Clausius to John Tyndall, 28 December 1859, Eidgenössische Technische Hochschule Zurich, Hs 227:5-163 (copies from the Royal Institution). For Clausius's subsequent comments on Mayer, see Rudolph Clausius to John Tyndall, 7 and 17 May 1862, and 7 and 15 June 1862.

4 For the general background, see Lloyd, *op. cit.* (note 2).

5 Hermann Helmholtz, 'Über die Erhaltung der Kraft (1862–63). Einleitung zu einem Cyclus von Vorlesungen, gehalten zu Karlsruhe im Winter 1862–63', in Hermann Helmholtz, *Vorträge und Reden*, 5th edn, vol. 1, pp. 186–229 (Friedrich Vieweg & Sohn, Braunschweig, 1903), at pp. 191–192; Hermann Helmholtz, 'Ueber das Ziel und die Forschritte der Naturwissenschaft. Eröffnungsrede für die Naturforscherversammlung zu Innsbruck 1869', in *ibid.*, vol. 1, pp. 367–398, at p. 380; Julius Robert Mayer to his wife, 18 September 1869, in Jacob J. Weyrauch (ed.) *Kleinere Schriften und Briefe von Robert Mayer. Nebst Mittheilungen aus seinem Leben* (J. G. Cotta, Stuttgart, 1893), pp. 445–446; Mayer's speech, in J. Daum, V. von Ebner and Hugo Graf Enzenberg (eds), *Tageblatt der 43. Versammlung Deutscher Naturforscher und Aerzte in Innsbruck vom 18. bis 24. September 1869* (Wagner'sche Universitäts-Buchhandlung, Innsbruck, 1869), pp. 40–44, at pp. 43–44.

6 Hermann Helmholtz to John Tyndall, 10 May 1862, Tyndall Collection, Royal Institution, London, 30/D1.2, Case 9, Packet 8. On the priority issue, see Weyrauch (ed.), *op. cit.* (note 5), pp. 442–443; Caneva, *op. cit.* (note 2), pp. 37–38, 262 and 331, notes the mental-illness issue

on pp. 9, 17 and 331. Karl von Vierordt told Helmholtz that Mayer was, 'unfortunately, very often very depressed; two years ago he threw himself out of a window, without, however, doing great damage.' (Karl von Vierordt to Hermann Helmholtz, 24 July 1854, HN 482.)

7 Crosbie Smith, *The science of energy: a cultural history of energy physics in Victorian Britain* (University of Chicago Press, 1998), pp. 180–182.

8 A. S. Eve and C. H. Creasey, *Life and work of John Tyndall* (Macmillan, London, 1945), pp. 94–104.

9 Lloyd, *op. cit.* (note 2), esp. pp. 212–220; Smith, *op. cit.* (note 7), pp. 183–191.

10 Cahan, *op. cit.* (note 1).

11 Peter Guthrie Tait to Hermann Helmholtz, 2 February 1867, HN 459; regarding the book's origins, see Cargill Gilston Knott, *Life and scientific work of Peter Guthrie Tait, supplementing the two volumes of scientific papers* (Cambridge University Press, 1911), p. 208.

12 Peter Guthrie Tait to Hermann Helmholtz, 1 and 27 March 1867, HN 459.

13 Peter Guthrie Tait to Hermann Helmholtz, 4 March 1868, HN 459. For the unfinished preface, see Peter Guthrie Tait to Hermann Helmholtz, 13 July 1868, HN 459.

14 Peter Guthrie Tait to Hermann Helmholtz, 28 July 1868, HN 459.

15 Peter Guthrie Tait, *Sketch of Thermodynamics* (Edmonston & Douglas, Edinburgh, 1868), pp. iii–viii, at pp. v-vii. Helmholtz's letter is reprinted in Hermann Helmholtz, *Wissenschaftliche Abhandlungen* (Johann Ambrosius Barth, Leipzig, 1882, 1883, 1895), vol. 1, pp. 71–73.

16 Peter Guthrie Tait, *Sketch of Thermodynamics*, 2nd rev. and extended edn (David Douglas, Edinburgh, 1877), pp. xiii–xviii.

17 Tait, *op. cit.* (note 16), p. 68. Even Tait's biographer, Cargill Gilston Knott, suggested that Tait's book was biased in favour of Joule at the expense of virtually everyone else. (See Knott, *op. cit.* (note 11), pp. 208 and 210.)

18 William Thomson to Hermann Helmholtz, 23 January 1870, HN 464.

19 Rudolph Clausius to John Tyndall, 6 January 1869, Eidgenössische Technische Hochschule Zurich, Hs 227:5-163 (copies from the Royal Institution).

20 Meetings of 13 May, 17 June and 4 November 1869, in *Minutes of Council of the Royal Society*, vol. 3 (1858–69) ([The Royal Society], London, 1870), pp. 473, 477 and 485.

21 Meetings of 5 May, 23 June and 3 November 1870, in *Minutes of Council of the Royal Society*, vol. 4 (1870–77) ([The Royal Society], London, 1878), pp. 15, 21 (quotation) and 28 (same quotation).

22 Sir Edward Sabine, 'November 30, 1870. Anniversary Meeting', *Proc. R. Soc. Lond.* **19**, 113–127 (1870–71), at pp. 123–124.

23 Meetings of 25 May, 15 June and 2 November 1871, in *Minutes of Council of the Royal Society*, *op. cit.* (note 21), pp. 56, 62 (regarding Mayer quotation), 63 (regarding Helmholtz and Grove quotations) and 72.

24 Sir Edward Sabine, 'November 30, 1871. Anniversary Meeting', *Proc. R. Soc. Lond.* **20**, 47–61 (1871–72), at pp. 54–56, quotations on p. 55.

25 H. M. Tuckwell (local secretary of the British Medical Association) to Hermann Helmholtz, 22 June 1868, HN 523.

26 Henry W. Acland to Hermann Helmholtz, 22 July 1868, HN 4.

27 J. Crompton (local secretary for the BAAS) to Hermann Helmholtz, March and May 1868, HN 96.

28 Cahan, *op. cit.* (note 1).

29 Henry W. Acland to Hermann Helmholtz, 20 April 1869, HN 4.

30 Henry W. Acland to Hermann Helmholtz, 10 April and 4 June 1870, HN 4; Hermann Helmholtz to H. W. Acland, 8 June 1870, Bodleian Library, University of Oxford, MS Acland, d.81, fol. 78r–79r.

31 Robert Salisbury to Hermann Helmholtz, 10 June 1870, HN 395.

32 'Comité Secret', *C. R. Hebd. Séanc. Acad. Sci.* **69**, 1385 (1869).

33 'Nominations', *C. R. Hebd. Séanc. Acad. Sci.* **70**, 27 (1870); 'Correspondance', *C. R. Hebd. Séanc. Acad. Sci.* **70**, 123 (1870).

34 For the nomination, Emil du Bois-Reymond *et al.* 1870; for the vote, Berlin-Brandenburgische Akademie der Wissenschaften, AHA, 'Auszug aus dem SitzungsProtokolle der phys.-math. Klasse vom 25. April 1870', p. 236; also *ibid.*, 5 May 1870, pp. 37–39.

35 Emil du Bois-Reymond to Jeannette du Bois-Reymond, 22 June 1870 (copy), Staatsbibliothek Preuβischer Kulturbesitz, Haus 2, Handschriftenabteilung, Dep. 5 (Runge-du Bois-Reymond Sammlung), K. 11, Nr. 5.

36 Roy M. MacLeod, 'Resources of science in Victorian England: the Endowment of Science movement, 1868–1900', in *Science and society 1600–1900* (ed. Peter Mathias), pp. 111–166 (Cambridge University Press, 1972).

37 William Thomson to Hermann Helmholtz, 28 January 1871, HN 464. (This letter is printed in N. Kurti, 'Helmholtz's choice', *Nature* **314**, 499 (1985).) See also N. Kurti, 'Reflections of an amateur "historian of science"', in *Physicists look back: studies in the history of physics* (ed. J. Roche), pp. 78–87 (Adam Hilger, Bristol, 1990), at pp. 79–82. Similarly, there may have been talk in 1865 of offering Helmholtz the professorship of physics at Oxford; at least, Helmholtz heard in 1866 that his name had come into consideration. For the hearsay evidence, see the two versions of a letter dated (by Ellen von Siemens-Helmholtz only) 11 April 1866 from Helmholtz to Anna Helmholtz, in *Anna von Helmholtz. Ein Lebensbild in Briefen* (ed. Ellen von Siemens-Helmholtz) (Verlag für Kulturpolitik, Berlin, 1929), vol. 1, pp. 130–131, and in Leo Koenigsberger, *Hermann von Helmholtz* (Friedrich Vieweg, Braunschweig, 1902–03), vol. 2, pp. 72–73. For speculations about this offer, see N. Kurti, 'Opportunity lost in 1865?', *Nature* **308**, 313–314 (1984).

38 Justus Olshausen to Hermann Helmholtz, 5 February 1871, HN 339. Anna Helmholtz to Pauline von Mohl, 9 February 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, p. 159, reports that, though the proffered conditions were very good, Helmholtz was thinking only of Berlin.

39 Helmholtz, Weierstraß, Kronecker, Kummer, Borchardt, 'Wahlvorschlag für Sir William Thomson (Lord Kelvin of Largs) (1824–1907) zum KM', 21 June 1871, in *Physiker über Physiker: Wahlvorschläge zur Aufnahme von Physikern in die Berliner Akademie 1870 bis 1929 von Hermann v. Helmholtz bis Erwin Schrödinger* (ed. Christa Kirsten and Hans-Günther Körber), pp. 80–82 (Akademie-Verlag, Berlin, 1975); for the broader context, see David Cahan, 'Helmholtz als führender Wissenschaftler an der Preußischen Akademie der Wissenschaften', in *Die Königlich Preußische Akademie der Wissenschaften zu Berlin im Kaiserreich* (ed. Jürgen Kocka, with Rainer Hohlfeld and Peter Th. Walther), pp. 277–313 (Akademie Verlag, Berlin 1999), esp. pp. 291–294.

40 William Thomson to Hermann Helmholtz, 30 March 1871, HN 464.

41 John Hughes Bennett to Hermann Helmholtz, 6 July 1871, HN 37; Alexander Crum Brown to Hermann Helmholtz, 19 April 1871, HN 72.

42 William Thomson to Hermann Helmholtz, 10 June [1871], HN 464.

43 William Thomson to Hermann Helmholtz, 14 June 1871, HN 464.

44 Peter Guthrie Tait to Hermann Helmholtz, 20 July 1871, HN 459.

45 Anna Helmholtz to Ida Freifrau von Schmidt-Zabiérow (her sister), 13 August 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, p. 166.

46 Silvanus P. Thompson, *The life of William Thomson, Baron Kelvin of Largs* (Macmillan Thompson, London, 1910), vol. 2, p. 612; William Thomson to George Gabriel Stokes, 6 October 1871, Cambridge University Library (Kelvin Correspondence K178).

47 Hermann Helmholtz to Anna Helmholtz, 20 August 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 166–167, quotation on p. 166; Knott, *op. cit.* (note 11), pp. 56 and 196–197 (which prints Tait's letter of 20 May 1871 to Helmholtz inviting him to stay with the Taits in St Andrews).

48 Thompson, *op. cit.* (note 46), vol. 2, p. 612.

49 Hermann Helmholtz to Anna Helmholtz, 24 and 27 August 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 167 and 168, respectively.

50 For this cruise with Thomson as centre point, see Crosbie Smith and M. Norton Wise, *Energy and empire: a biographical study of Lord Kelvin* (Cambridge University Press, 1989), pp. 736–740.

51 Peter Guthrie Tait to Hermann Helmholtz, 20 May and 17 August 1871, HN 459. (Tait had invited Helmholtz to stay with himself or Crum Brown, but he stayed with neither. See Peter Guthrie Tait to Hermann Helmholtz, 21 September 1871, HN 459.) William Thomson to George Gabriel Stokes, 6 October 1871, Cambridge University Library (Kelvin Correspondence K178) also notes that Thomson, his brother James, and Helmholtz had been sailing together in the West Highlands, as does James Thomson, *Collected papers in physics and engineering. Selected and arranged with unpublished material and brief annotations by Sir Joseph Larmor . . . and James Thomson* (Cambridge University Press, 1912), p. lxiii.

52 Hermann Helmholtz to Anna Helmholtz, 1 September 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 168–169.

53 Thomson quoted in Thompson, *op. cit.* (note 46), vol. 2, pp. 614–615. Cf. the remark in Hermann Helmholtz to [Anna Helmholtz?], 9 September 1871, in Thompson, *op. cit.* (note 46), vol. 2, p. 616, which is slightly different from that in the same letter given in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 170–171.

54 Hermann Helmholtz to Anna Helmholtz, 3 September 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, p. 169 (all quotations); William Thomson to his sister (Mrs King), 31 August 1871, in Thompson, *op. cit.* (note 46), vol. 2, p. 615.

55 Hermann Helmholtz to Anna Helmholtz, 6 September 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 169–170; William Thomson to his sister (Mrs King), 31 August 1871, in Thompson, *op. cit.* (note 46), vol. 2, p. 615.

56 Hermann Helmholtz to Anna Helmholtz, 10 September 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 170–171; this letter, dated 9 September 1871 and with additional material, is also published in Thompson, *op. cit.* (note 46), vol. 2, p. 616. On the Blackburns and Thomson, see Robert Fairley (ed.), *Jemima: the paintings and memoirs of a Victorian lady* (ed. and introd. by Robert Fairley) (Canongate, Edinburgh, 1988), pp. 18, 20, 28–29, 68 and 133–134; James Thomson to his wife, 8 September 1871, in Thomson, *op. cit.* (note 51), pp. lxiii–lxiv, at p. lxiv.

57 Hermann Helmholtz to Anna Helmholtz, 15 September 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 171–172. Cf. John Tatlock (Thomson's assistant) to George Gabriel Stokes, 6 October 1871 (this is actually the first part of a letter from Thomson to Stokes, 7 October 1871), in David Wilson (ed.), *The correspondence between Sir George Gabriel Stokes and Sir William Thomson, Baron Kelvin of Largs* (Cambridge University Press, 1990), vol. 2, pp. 362–364, at pp. 363–364; James Thomson to his wife, 14 September 1871, in Thomson, *op. cit.* (note 51), pp. lxiv–lxv, at p. lxv; Thompson, *op. cit.* (note 46), vol. 2, p. 747, notes the cruise and the measurements; Smith and Wise, *op. cit.* (note 50), p. 739.

58 Hermann Helmholtz to Anna Helmholtz, 15 September 1871, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 171–172.

59 William Thomson to Hermann Helmholtz, 29 October 1871, HN 464 (regarding the Strutts); James Thomson to his wife, 8 September 1871, in Thomson, *op. cit.* (note 51), pp. lxiii–lxiv, at p. lxiv (regarding Ferguson and John Millar Thomson).

60 William Thomson to Hermann Helmholtz, 29 October 1871, HN 464; for the quotation, see Hermann Helmholtz to William Thomson, 4 November 1871, Edinburgh University Library, Special Collections, Gen. 2169, Helmholtz letters.

61 Meetings of 16 May, 20 June and 7 November 1872, in *Minutes of Council of the Royal Society*, *op. cit.* (note 21), pp. 104, 110 (quotation) and 126.

62 William Thomson to Hermann Helmholtz, 11 December 1872, HN 464.

63 William Thomson to Hermann Helmholtz, 8 January 1873, HN 464.

64 Peter Guthrie Tait to Hermann Helmholtz, 4 April 1873, HN 459.

65 Meetings of 15 May and 19 June 1873, in *Minutes of Council of the Royal Society*, *op. cit.* (note 21), pp. 181 and 185 (quotation).

66 John Tyndall to Hermann Helmholtz, 25 September 1873, HN 477.

67 *Orden pour le mérite für Wissenschaften und Künste. Die Mitglieder des Ordens* (Gebr. Mann, Berlin, 1975 and 1978), vol. 2, p. 316.

68 Anna Helmholtz to Robert von Mohl, 16 November 1873, in Siemens-Helmholtz (ed.), *op. cit.* (note 37), vol. 1, pp. 174–175 (this letter is misdated in Siemens-Helmholtz (ed.), as having been written in 1871; it must be 1873, because it refers both to Helmholtz's deanship of the Philosophical Faculty at Berlin, which occurred in 1873–74, and to the fact that he had recently won the Copley Medal); W. H. Miller (Foreign Secretary of the Royal Society) to Hermann Helmholtz, 8 November 1873, Awards, Honorary Memberships, etc. in Siemens Archiv (Signatur.: Helmholtz. 6.LL 494). The council voted the award for Helmholtz at its meeting of 6 November 1873, in *Minutes of Council of the Royal Society*, *op. cit.* (note 21), p. 193.

69 John Tyndall to Hermann Helmholtz, 13 November 1873, HN 477.

70 Hermann Helmholtz to John Tyndall, 22 November 1873, Tyndall Collection, Royal Institution, London, 30/D2.12, Case 9, Packet 8.

71 Sir George Biddell Airy, 'December 1, 1873. Anniversary Meeting', *Proc. R. Soc. Lond.* **22**, 1–20 (1873–74), at pp. 10–11.

72 Hermann Helmholtz to E. Thompson (honorary secretary to the Society), 15 December 1873, The Royal Society of Medicine, Library, London. See also Hermann Helmholtz to E. Thompson, 27 March 1874, *ibid.*

73 Hermann Helmholtz to Sir, 5 May 1874, Siemens Archiv, Signatur: Helmholtz 6.LL496.