The Morals of Measurement

The Morals of Measurement is a contribution to the social histories of quantification and of electrical technology in nineteenth-century Britain, Germany, and France. It shows how the advent of commercial electrical lighting stimulated the industrialisation of electrical measurement from a skilled labour-intensive activity to a mechanised practice relying on radically new kinds of instruments. Challenging traditional accounts that focus on metrological standards, this book shows instead the centrality of *trust* when measurement was undertaken in an increasingly complex division of labour with manufactured hardware. Case studies demonstrate how difficult late Victorians found it to agree upon which electrical practitioners, instruments, and metals were most trustworthy and what they could hope to measure with any accuracy. Subtle ambiguities arose too over what constituted 'measurement' or 'accuracy' and thus over the respective responsibilities of humans and technologies in electrical practice. Running alongside these concerns, the themes of body, gender, and authorship feature importantly in controversies over the changing identity of the measurer. In examining how new groups of electrical experts and consumers construed the fairness of metering for domestic lighting, this work charts the early moral debates over what is now a ubiquitous technology for quantifying electricity. Accordingly readers will gain fresh insights, tinged with irony, on a period in which measurement was treated as the definitive means of gaining knowledge of the world.

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The Morals of Measurement

Accuracy, Irony, and Trust in Late Victorian Electrical Practice

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Abbreviations

BJHS	*British Journal for the History of Science*
BAAS	British Association for the Advancement of Science
ICE	Institution of Civil Engineers

The following three names applied successively to one and the same institution:

STE	Society of Telegraph Engineers (1871–80)
STEE	Society of Telegraph Engineers and Electricians (1881–8)
IEE	Institution of Electrical Engineers (1889–)

Notes
Where no author is specified, publications were anonymous. The names of publishers are cited only for twentieth-century books.

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One of the great difficulties experienced by people in mastering the *quantitative* science of electricity, arises from the fact that we do not number an electrical sense among our other senses, and hence we have no intuitive perception of electrical phenomena . . . an infant has distinct ideas about hot and cold, although it may not be able to put its ideas into words and yet many a student of electricity of mature years has but the haziest notions of the exact meaning of high and low potential, the electric analogues of hot and cold.

William E. Ayrton, *Practical Electricity*, 1887, Preface

Every practice requires a certain kind of relationship between those who participate in it. Now the virtues are those goods by reference to which, whether we like it or not, we define our relationships to those other people with whom we share the kinds of purposes and standards which inform practices.

Alasdair MacIntyre, 'The Nature of the Virtues', *After Virtue*, 2nd edition, 1985, p. 191

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Preface

When electrification is produced by friction, or by any other known method, equal quantities of positive and negative electrification are produced . . . The electrification of a body is therefore a physical quantity capable of measurement . . . While admitting electricity, as we have now done, to the rank of a physical quantity, we must not too hastily assume that it is, or is not, a substance, or that it is, or is not, a form of energy, or that it belongs to any known category of physical quantities.

James Clerk Maxwell, *Treatise on Electricity and Magnetism*, 1873[1]

The first step is to measure whatever can be easily measured. This is O.K. as far as it goes. The second step is to disregard that which can't be measured or give it an arbitrary quantitative value. This is artificial and misleading. The third step is to presume that what can't be measured easily isn't very important. This is blindness. The fourth step is to say that what can't easily be measured doesn't really exist. This is suicide.

Daniel Yankelovich, interview with George Goodman, c. 1973[2]

As James Clerk Maxwell knew perhaps better than anyone else, dealing with electricity was no dull or easy matter. Like many contemporaries in industrial and academic spheres who sought to harness electricity to technological ends, he laboured extensively to comprehend its complex and occasionally shocking behaviour. Yet as Maxwell hinted early on in his famous *Treatise*, there was much uncertainty about what electricity actually *was*. Natural philosophers, electricians, and telegraphists could not agree among themselves about whether electricity was a form of energy, or constituted out of one or possibly two negatively or positively charged fluids (whether material or immaterial), or perhaps was even something hitherto altogether unknown.

1 James Clerk Maxwell, *Treatise on electricity and magnetism*, 1st edition, 2 Vols., London: 1873. Unless otherwise specified, all quotations are from the 3rd edition (ed. J. J. Thomson), 1891, reprinted New York: Dover, 1954; quotation on p. 38.

2 Daniel Yankelovich from interview quoted in 'Adam Smith' [pseudonym of George J.W. Goodman], *Supermoney*, London: Michael Joseph, 1973, p. 286. The context of Yankelovich's comment was a sharp critique of the U.S. government's approach to quantifying human losses in the Vietnam War.

They did at least share with Maxwell, though, the conviction that electricity was in fact measurable. Hence many adopted the pragmatic strategy of focussing on those manifestations of electricity that they thought could most easily be assigned stable numerical properties.

Or at least they supposed they could, for, in fact, efforts to measure even the most mundane electrical performance could be imbued with problems and ambiguities that arose for a wide variety of reasons. Not least among their concerns was an emerging question: what actually *constituted* the 'measurement' of a physical quantity? Was it necessarily a laborious activity of 'absolute' determination in terms of mass and length, or could it just be 'relative' comparison against a convenient calibrated commercial standard as was common in telegraphy from the late 1850s? Then again, could measurement be constituted by an instantaneous glance at the deflection of a needle or light-spot over the dial of a pre-calibrated instrument – as electrical-lighting engineers contended in regard to the new industrial instruments they developed in the 1880s? It is the vivid controversies that arose from these problems and ambiguities that form the substance of much of this book.

What then could the themes of 'morals' do to help the historical recovery of heterogeneous and contested technical practices of electrical measurement in the later Victorian period? My title is neither oxymoronic nor merely alliterative. It plays instead on the twofold signification of morals, drawing first on the historiographical *lessons* gleaned from attempting to reconstruct the diverse Victorian projects of quantifying electrical performance. On the one hand, it is about how physicists, chemists, electricians, and electrical engineers tried to measure what mattered to them for their very different reasons.[3] It is also about how they often disagreed interestingly about how to measure electricity and what could or *should* be measured. Much of their disagreements centred on the highly specialized technologies they deployed

[3] Here I allude to the wide range of scholarship on the complexity of the science–technology relationship in the nineteenth century: Donald Cardwell, *Technology, science and history: A short study of the major developments in the history of Western mechanical technology and their relationships with science and other forms of knowledge*, London: Heinemann, 1972; Ronald Kline, 'Science and engineering theory in the invention and development of the induction motor, 1880–1900', *Technology and Culture*, 28 (1987), pp. 283–313; Bruce J. Hunt, 'Insulation for an empire: Gutta Percha and the development of electrical measurement in Victorian Britain', in F. A. J. L. James (ed.), *From semaphore to shortwaves*, London: Royal Society of Arts, 1998, pp. 85–104; Sungook Hong, 'Historiographical layers in the relationship between science, technology', *History and Technology*, 15 (1999), pp. 289–311. These authors show how engineering endeavours furnished not only many of the theoretical and practical problems that occupied practitioners of physics and natural philosophy, but also the resources and personnel with which to solve them. In applying this approach to the history of measurement, my account can be contrasted with historiographies that present quantification as driven by a disembodied and culturally invasive 'spirit'. See, for example, Tore Frängsmyr, John Heilbron, and Robin E. Rider, *The quantifying spirit in the eighteenth century*, Berkeley: University of California Press, 1990.

to make electrical measurements beyond the bodily capacities or endurance of ordinary humans. Accordingly I focus much on the instruments through which my protagonists articulated their value-laden and thus often divergent practices of electrical measurement. This generally occurred in colourful discussions with instrument-makers and fellow instrument-users about which user-centred values should be incorporated into the construction of such instruments for their particular purposes and contexts.

And it is in this value-ladenness in the practices and instrumentation of measurement that my other moral theme lies. I explore the (limited) extent to which contemporaries construed judgements of trustworthiness in measurement to have some form of moral dimension. Accordingly I explore how judgements of fairness, fidelity, and honesty were used to decide which electrical practitioners and instruments should be trusted or distrusted in measurement work, and why. Historians really should not, of course, be squeamish about the intrusion of moral issues into their analytical discourse. Moralistic imperatives and judgements pervade even the most radical recent accounts in history and sociology of science.[4] Some sociologists have even argued that it is futile and counterproductive to seek neutrality when analysing scientific controversies.[5] And for the reflective historian, it is impossible to avoid making some sort of judgement – albeit often tacit – about the fair representation of the integrity (or self-interestedness) of historical actors. And if historians cannot avoid making morally loaded judgements of this sort in their everyday work, it is reasonable to suppose that past scientists and technologists might have interpreted and judged each others' actions in similarly evaluative terms.

[4] Schaffer and Shapin explicitly side with Hobbes against the many partisanly Boyle-centred accounts of late seventeenth-century science. Simon Schaffer and Steve Shapin, *Leviathan and the airpump: Hobbes, Boyle and the experimental life*, Princeton, NJ: Princeton University Press, 1985. Ashmore represents Blondlot's N-Ray experiments as a victim of unfair debunking experiments in Malcom Ashmore, 'The theatre of the blind: Starring a Promethean prankster, a phoney phenomenon, a prism, a pocket, and a piece of wood', *Social Studies of Science*, 23 (1993), pp. 67–106. In laying out a manifesto for a sociology of knowledge that treated claims for scientific truth and falsity with a 'symmetrical' impartiality, Bloor contends that sociologists' previous refusal to countenance such an approach amounted to a 'betrayal' of their disciplinary standpoint; David Bloor, *Science and social imagery*, London: Routledge, 1976, p. 1. For Brian Wynne's partisan role in opposing the nuclear power industry whilst undertaking a sociological analysis of it, see Brian Wynne, *Rationality and ritual: The Windscale inquiry and nuclear decisions in Britain*, Chalfont St Giles: British Society for the History of Science, 1982.

[5] Pam Scott, Eveleen Richards, and Brian Martin, 'Captives of controversy: The myth of the neutral social researcher in contemporary scientific controversy', *Science, Technology and Human Values*, 15 (1990), pp. 474–94; Dick Pels, 'The politics of symmetry', *Social Studies of Science*, 26 (1996), pp. 277–304; B. Wynne 'SSK's identity parade: Signing up, off-and-on', *Social Studies of Science*, 26 (1996), pp. 357–92. The last two papers appear in a volume of *Social Studies of Science* co-edited by Eveleen Richards and Malcom Ashmore titled 'The politics of SSK: Neutrality commitments and beyond'.

In seeking to identify the moral features of a technical practice such as electrical measurement I do not assume that all practitioners necessarily pursued moral agendas – whether morality be construed in terms of individual obligation (deontology), welfare maximization (utilitarianism), fair treatment (rights theory), or good conduct (virtue theory).[6] Victorian engineers and scientists certainly did not always act altruistically or impartially, nor were they systematically disinterested, communally oriented, or sceptical in all their claims. Indeed, on close inspection much of their conduct bears out Trevor Pinch's point that such norms of professionally virtuous behaviour (e.g., as identified by Robert Merton) are most obviously manifested in the post hoc justification of action rather than in its initial motivation.[7] But whatever the virtues or vices of the measurer(s) involved, their measurements could be intrepreted *by other* observers – especially critics – as bearing a significance that went beyond the merely technical or epistemological. The morals of measurement could be seen in at least four ways: in the *presuppositions* of a measurement; what was fair to assume about the integrity of previous measurers in the field? In the *performance* of a measurement; did its conduct instantiate trustworthy practices and appropriate experimental virtues? In the *reporting* of a measurement; was the written (published) account an honest and impartial summary of the performance? And in the *ramifications* of a measurement; what benefits – if any – might the quantitative information generated bring to others?

6 Not all mutual 'obligations' of past practitioners can be simply represented as essentially 'moral' in character: see Steve Shapin, *A social history of truth: Civility and science in seventeenth century England*, Chicago: University of Chicago Press, 1994, pp. 310–11. For a general study of the relations between knowledge and obligations, see Morton White, *What is and what ought to be: An essay on ethics and epistemology*, New York/Oxford: Oxford University Press, 1981. For some interesting discussion of the moralization of science, see Robert Proctor, *Value-free science: Purity and power in modern knowledge*, London/Cambridge, MA: Harvard University Press, 1991; Anna Mayer, 'Moralizing science: The uses of science's past in the 1920s', *British Journal for the History of Science*, 30 (1997), pp. 51–70; and John Krige and Dominique Pestre, 'Introduction', in J. Krige and D. Pestre, (eds.), *Science in the twentieth century*, Amsterdam: Harwood Academic, 1997, pp. xxi–xxxv, discussion on pp. xxi–xxii.

7 Robert K. Merton, 'The normative structure of science' [1942], in *The sociology of science: Theoretical and empirical generalizations*, Chicago: University of Chicago Press, 1973, pp. 267–78; Paul Feyerabend, *Against method*, London: New Left Books, 1975; Trevor Pinch, 'The sociology of the scientific community', in Robert Olby, Geoffrey Cantor, John Christie, and Jonathan Hodge (eds.), *Companion to the history of modern science*, London: Routledge, 1990, pp. 87–99, discussion on p. 89. Nevertheless, Rom Harré claims that the scientific community is 'morally superior to every other form of human association'; R. Harré, *Varieties of realism: A rationale for the natural sciences*, Oxford: Blackwell, 1986, pp. 1–2, 6–7. See further discussion in the next chapter; for contrasting studies of the widespread persistence of fraudulent science, see William Broad and Nicholas Wade, *Betrayers of the truth*, Oxford: Oxford University Press, 1985.

This last issue leads me to the moral–political point sharply delineated by the American social theorist Daniel Yankelovich in the quote in the opening of this Preface. Yankelovich's concern lies in what is *lost* and who are the *losers* when measurement is treated as the definitive arbitrating practice in creating representations of the world. He makes a stark observation about those measurers who are unreflexively enamoured of the apparently unique efficacy of measurement. He notes that, from the productivity and instrumental utility of their quantitative work, measurers can convince themselves and their allies that measurability is the only important feature of epistemology, and thence drift into self-serving circular arguments about the worldly understanding to be attained through measurement. Yankelovich identifies a three-stage slippage: That which cannot be (easily) measured can be at first disregarded, then treated as unimportant, and then indeed in the extreme case treated as if it does not really exist at all. He thus highlights a pernicious slide from a tendentious epistemological claim to a distinctly sinister moral claim and a rather nihilistic ontological claim. If accepted at face value, such claims enable measurers to have a monopoly of expertise in determining what can be considered to exist and what can be a legitimate matter of human concern – the only things that matter are those in which they have the predominant expertise.

If we follow the force of Yankelovich's observation, it is all too evident that if privileged significance is attached only to that which is easily measurable, then those people who cherish what cannot easily be thus quantified are likely to experience injustice or at least marginalization. Less extreme, but of great significance to this volume, is that such unfortunates may find their positions all too easily devalued by quantitative experts as deficient in (numerical) evidential support or even as grounded on mere speculation or delusion. Much has been made in this regard of a passing comment made in 1883 by William Thomson (later Lord Kelvin) that knowledge claims are 'meagre and unsatisfactory' unless based on the results of measurement. When extended to domains beyond that of the physical sciences – notably medicine and education – critics have condemned this partisan valorization of the easily measurable over the unquantifiable as the 'curse of Kelvin'.[8]

[8] Alvan R. Feinstein, 'Clinical biostatics XII: On exorcising the ghost of Gauss and the curse of Kelvin', *Clinical Pharmacology and Therapeutics*, 12 (1971), pp. 1003–16, esp. p. 1004. One critic of unreflective measurement invoked the antireductionist wisdom of Daniel Yankelovich as a poignant antidote to the 'Curse of Kelvin'; see letter from Sheldon H. White to the educationalist, Jerrold R. Zacharias, 7 November 1978, cited in Jack S. Goldstein, *A different sort of time: The life of Jerrold R. Zacharias*, London/Cambridge, MA: MIT Press, 1992, p. 287. By contrast, Ian Hacking notes that scientists seeking to defend contentious quantitative work against critical sceptics have often borrowed Thomson's words to bolster their position; Ian Hacking, *Representing and intervening*, Cambridge: Cambridge University Press, 1983, p. 242. For further discussion of Thomson's 1883 views on measurement, see Chapter 1 of this volume.

Who could deny that a politics of exclusion is readily facilitated by successful moves to promote a monopoly of expertise based on skill-intensive and resource-intensive practice of measurement? Subsequent chapters show that late Victorian debates on electrical matters were dominated by those physicists, chemists, electricians, telegraphists, engineers, or instrument-makers who had both the expert skill and access to resources to undertake sophisticated and lengthy electrical measurements. By contrast, there is an absence of voices from an older tradition of workers specializing in technologies of 'electrical display', as discussed by Iwan Morus. Whilst theirs was a form of practical virtuosity which by the last third of the nineteenth century still commanded public enthusiasm, it did not win such practitioners a place in debates at the Royal Society, Physical Society, or Institution of Electrical Engineers; nor did it win them many publications in technical journals of natural philosophy, such as *The Philosophical Magazine* or of the electrical trade, such as *The Electrician*. Significantly, though, there were some commercially important groups of consumers who were granted an indirect voice in some debates on how to quantify the behaviour of electricity, one prominent example being the tiny but growing elite of electric-lighting consumers in the 1880s and 1890s. Yet to learn about how customers' grievances at unreliable or misleadingly supplied electrical power affected the quantifying practices of electricians and engineers, we generally have to rely on the somewhat partisan testimony of the latter. And entirely absent from such debates were the voices of citizens who were not consumers of electrical products but whose quality of life was palpably diminished by the advent of noisy and polluting new generating stations and garish outdoor arc lighting.[9] *Their* disaffection was not something that the electrical community made any gesture towards quantifying: In Yankelovich's terms the electrical experts considered such disaffection as either not mattering or non-existent.

Ironically, however, we shall see that the experts discussed in this book kept encountering significant limits to their technologically enhanced capacities to quantify even straightforward electrical matters. In several instances, and in direct conflict with Thomson's identification of knowability with measurability, it proved extremely problematic to measure some electrical parameters that were considered not only to be real (despite being unquantifiable) but indeed of great technological importance. In Chapter 5 I examine the self-induction of a moving alternator as a case in point and in Chapter 6 the actual amount of light consumed by a household installed with electric illumination. In both cases we will see how debate shifted – albeit not without challenges, some moral in nature – from what arguably *should* have

[9] See 'Lines to the electric light at the G.W. Railway terminus', published by the *St James Gazette* in 1888, cited in Robert H. Parsons, *The early days of the power station industry*, Cambridge: Cambridge University Press, 1940, p. 42.

been measured to the kinds of electrical parameters that *could* easily and inexpensively be measured.

In a vein of Rortyian 'irony' this work explores the nature of limits in scholarly enterprises: both the limited power of interpretive themes, and the limits to which these themes can reasonably be taken. I show that practitioners acknowledged distinct limits to the power of electrical measurement to capture both the nature of electrical behaviour and the performance of electrical technology in relation to human demands. Thus although I argue for the importance of measurement in attempts to deal with the mysteries of electricity, I show also what a problematic and bounded enterprise it was. And although I argue for the importance of recognizing moral concerns in late nineteenth-century endeavours of science and technology, I also embrace the interpretive limitations of such a pursuit.[10] Whilst focussing often on the notion of trust as the important 'moral' dimension to measurement, I suggest that trust cannot be seen as an exclusively moral category, nor that moral considerations pertaining to trust are omnipresent in measurement practice. And accordingly I explore how practitioners used the complex qualitative and quantitative languages of 'accuracy' or 'degree of accuracy' to articulate the limits to which they considered they could trust – or should be able to trust – their measurements.[11]

As we shall see, the relationship between the limits of desirable accuracy and achievable accuracy was not stable. Although these converged when practitioners learned to live within the horizons offered by their instruments, they diverged when the demands of industrial efficiency or customer satisfaction called for greater robustness, celerity, transparency, sensitivity, or trustworthiness than extant instruments could be made to furnish. As Matthias Dörries has noted, it is the recurrent limitations of instruments rather than their 'successes' that lead to their users' and makers' trying to refine or adapt their construction and operation.[12] Throughout this book, I reiterate Dörries' insight and extend it to the ways in which problematic attempts to extend measurement practice into hitherto new domains of electromagnetism generated a reflexive awareness that understandings of what could or should constitute measurement were in need of re-examination. This reflexive awareness was not necessarily a matter of increased rigour: It was more often a matter of pragmatic compromise to abandon older practices to meet new desiderata.

[10] See Richard Rorty, *Contingency, irony and solidarity*, Cambridge: Cambridge University Press, 1989, pp. 73–95, esp. pp. 73–4. An alternative term that some readers might prefer to 'irony' here is 'finitism' or 'anti-reductivism.'

[11] A number of historians have shown that the meanings and significance of such terms are ineluctably embedded within the contingencies of cultural values. See M. Norton Wise (ed.), *The values of precision*, Princeton, NJ: Princeton University Press, 1995, and Chapter 2 of this volume for further discussion.

[12] Matthias Dörries, 'Balances, spectroscopes, and the reflexive nature of experiment', *Studies in the History and Philosophy of Science*, 25 (1994), pp. 1–36.

Put crudely, my overarching thesis is that electrical measurement underwent a form of 'industrialization' in the last two decades of the nineteenth century.[13] In the earlier period covered by this book, the 1850s to 1870s, physicists and telegraphic electricians generally relied to a great extent on their own manual skill and resourcefulness to manipulate instruments into the correct configuration to take a reading. They tended, moreover, to take great personal care and time to establish the propriety of calibrations, calculations, and results obtained in measurement activity. With the rise of electric lighting in the following two decades, however, such reliance on time-consuming and laborious care was displaced by the adoption of labour-saving and time-saving techniques of instrument operation and reading. Sophisticated automated (and fallible) instrument mechanisms were developed that displaced much of the interpretive skill from the human user to the ingenuity of designer and concomitantly shifted much of the all-important labour of calibration from user to instrument-maker. Measurement using 'direct-reading' ammeters and voltmeters thus became more like the 'minding' of automated factory machinery and less like the virtuosic skilled effort of a self-reliant expert. As we shall see, the shifting patterns of trust engendered in this new division of labour in measurement work generated debates which pitted the integrity of labour and virtues of mechanization in ways that echoed earlier controversies over factory mechanization.[14] Readers of this volume may wish to ponder the long amnesia about such debates. By reading what follows, they can recover how it became possible for them to trust readings they take in a glance from dials on their car dashboards or from rotating indices on their household electricity meters – a practice barely recognizable to mid-Victorian forbears as any kind of measurement, *sensu strictu*.

Following my detailed analysis of the role and character of trust in instrumental measurement practice in Chapter 1, I move in Chapter 2 to a deconstruction of the apparently simple notions of electrical measurements and accuracy to which late Victorians subscribed. Successive chapters are then devoted in a sense to considering the material, moral, and managerial problems of measuring specific electrical parameters: electrical resistance (Chapter 3), electrical current (Chapter 4), self-induction (Chapter 5), and domestic electrical consumption (Chapter 6). Each bears out my claim that problems of agreeing how to measure in a way were *not* solved by universalized use of metrological standards – these were neither necessary nor sufficient for this purpose. In each case, questions were raised about whether

[13] I use the term 'industrialization' here following Wolfgang Schivelbusch, *Disenchanted night: The industrialization of light in the nineteenth century* (trans. A. Davies) Oxford/New York: Berg, 1988.

[14] Maxine Berg, *The age of manufactures, 1700–1820: Industry, innovation and work in Britain*, 2nd edition, London: Routledge, 1994.

the parameter could be measured at all, and if so whether it could practicably be measured to within an appropriate 'degree of accuracy' in a suitably disinterested fashion. We shall thus see that William Thomson's advice to contemporaries to seek the safest knowledge of things through measurement was subverted by the difficulties of knowing which would be the most trustworthy methods, materials, and instruments to use in measurement.

In addition to these specific topics in the historiography of measurement, these chapters also address issues central to contemporary historiography of science and technology. A major theme in Chapter 2 is who could be the author of measurement – a question as contentious as attributions of *authorship* to texts. The complex division of labour that developed in the skilled design, manufacture, and pre-calibration of direct-reading instruments during the 1880s reduced the role of users to such a skill- and labour-free involvement that some traditionalists denied they were taking measurements at all. Chapter 3 explores how interpretive flexibility occurs in judgements of trust. In evaluations, so many measurements in constructing resistance standards were non-reproducible: According to the charity of their judgement, critics could impute various degrees of untrustworthiness to techniques, constitutive metals, or their human spokespersons. In Chapter 4, I explore the theme of how the bodies of measurers – and not just their eyes and brains – mattered in the measurement process. The various techniques of taking *readings* in measurement activities presupposed a particular kind of spatio-temporal configuration between instrument and reader, and this required different forms of bodily deportment – not all of which were equally acceptable to all practitioners. In Chapter 6, I consider briefly how the gendered identity of the putative measurer enters into considerations of the trustworthiness of measurement. I show how one female expert on electrical matters was technically adept at reading the electric meter but advised her readers to defer to male householders – as legally responsible for paying for the luxury of electric lighting – the general prerogative of taking such readings.

Although such familiar heroic masculine figures as William Thomson and James Clerk Maxwell often appear in my story it is not in their traditional role as abstract theorists, but rather as technologically informed experts on electrical measurement practice whose judgements impinged on the everyday lives of electricians and kindred workers. The foreground is filled by less-often-discussed but equally important characters such as the (physically disabled) chemist Augustus Matthiessen and his rival for expertise in electrical metals, the Prussian industrialist and telegraph entrepreneur Werner von Siemens. The telegraphic expertise of Robert Sabine, Harry Kempe, and Latimer Clark earns them a place as writers of major handbooks on electrical measurement techniques that were often read alongside Maxwell's *Treatise on Electricity and Magnetism* (1873) as a guide to refined techniques of laboratory measurement. Such works were familiar to William Ayrton as a telegraphic expert in India and Japan up to 1878 and continued to be sources of reference for him as City & Guilds Professor of physics and electrical engineering, first at Finsbury Technology in London then at South Kensington from 1884 to 1885. As a major teacher, instrument designer, and suffragete sympathizer, Ayrton takes up a major place in several chapters largely because of his work with collaborator John Perry in promoting the innovation of direct-reading instruments. A biographical piece in the *Electrical Engineer* for January 1889 argued that, although to the public Ayrton had played a major role in explaining the new technologies of electric light and power, for the 'practical man' his name more closely connected with 'simple and portable measuring instruments' than with anything else, as such instruments had largely been manufactured and used from 'his designs'.[15] Whilst thus aiming in part to illustrate Ayrton's important role in the history of measurement instruments, this book is not, however, a biography of Ayrton – an important enterprise that no one to my knowledge has yet attempted.

A recurrent critic of Ayrton at meetings of both the Institution of Electrical Engineers and the Institution of Civil Engineers was the aristocratic mechanical engineer turned freelance consultant electrician, James Swinburne. It was Swinburne who most often challenged Ayrton's pretensions as a protégé of Sir William Thomson to omniscience in matters of measurement, and Ayrton's somewhat quixotic agenda of attempting to render all things in the electrical domain subject to measurement. Appointed Professor of electrical engineering at King's College London in 1890, John Hopkinson was another eminence who crossed swords with Ayrton. As Cambridge-trained mathematician and UK consultant for Edison's direct-current supply system Hopkinson was reknowned for his fierce intellect and tongue, as well as for his controversial propensity for applying Cambridge mathematics to electrical machinery where other engineers considered it to have no place. An important part of the electrical community in which Ayrton, Swinburne, and Hopkinson worked was the network of instrument-makers who not only produced the instruments used by them on a daily basis, but regularly commented on the measurements produced with their devices. Accordingly I set into context the roles of Alexander Muirhead, Sydney Evershed, Kenelm

[15] Anonymous, 'Prof. W.E. Ayrton F.R.S.', *Electrical Engineer*, 3 (1889), p. 66. For further details of Ayrton's life, see Graeme Gooday, 'William Edward Ayrton', *New Dictionary of National Biography*, Oxford: Oxford University Press, forthcoming 2004. Biographical sources used include Phillip Hartog, 'Professor W. E. Ayrton: A biographical sketch', *Cassier's Magazine*, 22 (1902), pp. 541–4; 'Anonymous, 'William Edward Ayrton, F.R.S.', *Electrician*, 28 (1892), pp. 346–7; Evelyn Sharp, *Hertha Ayrton, 1854–1923: A memoir*, London: 1926; John Perry, 'William Edward Ayrton', *Proceedings of the Royal Society*, 85 A (1911), pp. i–viii; John Perry, 'Obituary: William Edward Ayrton, F.R.S.', *Electrician*, 62(1908), pp. 187–8; William Mordey and John Perry, 'Death of Professor W.E. Ayrton', *JIEE*, 42(1909), pp. 1–6; John Perry, 'William Edward Ayrton, F.R.S.', *Nature* (London), 79 (1908), pp. 74–5.

Edgecumbe, Marcel Deprez, Edward Weston, and Sebastian Ferranti, as well as such companies as Acme, Hookham, Elliots, and Siemens.

Elsewhere in the book, well-known characters appear in less familiar guises. Norman Campbell, more famous for his philosophical studies of science, is cast as a disaffected critic of accounts of measurement he encountered in his student period at *fin de siècle* Cambridge. H. G. Wells makes a cameo appearance as an unruly trainee science teacher, subverting his South Kensington training in measurement and instrument-making practices. Whilst male characters are very much in the foreground of this study of late Victorian science and technology, I show that several women were closely and importantly involved in the electrical work of their spouses and families – albeit in ways that are still a great challenge for the historian to recover. Eleanor Sidgwick, Elizabeth Muirhead, Gertrude Ferranti, and Hertha Ayrton thus appear in my narrative, and I devote considerable attention in my last chapter to the role of Alice Gordon – more familiarly known as 'Mrs J.E.H. Gordon' – in promoting domestic electrical lighting to British women and men in the early 1890s.

It was of course William Thomson who once suggested that the topic of measurement was simply 'teeming with interest',[16] and I owe substantial debts to the two people who first got me interested in the history of electrical measurement. Much of what I know about the history of electricity I learned from Andrew Warwick's undergraduate classes at the University of Cambridge in 1985–6. And it was Crosbie Smith at the University of Kent at Canterbury who introduced me to the history of measurement while supervising the doctoral thesis in 1986–9 that is the very remote ancestor of this book. Without their long-lasting inspiration this book would never have been written. Norton Wise too has exerted a most benign influence on my research, not least by inviting me to a workshop at Princeton 1992 at which I could develop my arguments on the moral aspects of late Victorian measurement. Sophie Forgan has been a cherished collaborator on a number of related historical projects on institutions and gender issues. I have also drawn much inspiration from the work, hospitality, and friendship of Bruce Hunt, Ben Marsden, Kathy Olesko, and Jack Morrell who over the past decade have shared their views on Victorian science and engineering with me. Without their help, this book would have been greatly impoverished.

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[16] William Thomson, 'Scientific laboratories', *Nature* (London), 31 (1885), p. 411.

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Graeme Gooday, Leeds, August 2002