communications of its citizens that were its main clientele. Evidently the ambiguity in this matter raised questions about how far Danish citizenship incorporated both rights to privacy in telegraphic communications and their obligation to allow the state complete peacetime surveillance of whatever passed over its networks.

Focusing on a subsequent wartime context is Elizabeth Bruton's study of 'The cable wars: military and state surveillance of the British telegraph cable network during World War One'. Bruton shows how communication infrastructure developed in peacetime was not simply appropriated for the mundane facilitation of modern warfare: the aggressive destruction of enemy communication infrastructure was evidently a vital (if rarely visible) feature of successful military campaigns by Britain and its Great War allies. Equally important in infrastructural management was their constant discreet surveillance of less developed networks operated by Germany and its allies, and thus the strategically valuable interception of the notorious Zimmerman telegram in April 1917. Crucial to this, as Bruton emphasizes, was the significant amount of redundancy deliberately built into the telegraph networks of Britain and its allies prior to the outbreak of the First World War to ensure their continued operation even while under attack and attacking others.

The lack of an index in this volume makes it difficult for the reader to track its common themes across the other chapters. And one might have wished for deeper meditations about what is to be learned about comparing communication and transport infrastructure in both peacetime and war. Moreover, one might have wished for more reflection on the provenance of the very term 'infrastructure' as largely deployed post-Second World War, apparently as an artefact of that era's emerging military–industrial complex. Nevertheless, to escape the transience of the localized contingency-laden case study, this volume shows us that the persistence of infrastructure deserves attention in any history of modern science, technology and medicine.

Graeme Gooday
University of Leeds

Roland Wittje, **The Age of Electroacoustics: Transforming Science and Sound**. Cambridge, MA and London: MIT Press, 2016. Pp. 297. ISBN 978-0-262-03526-2. $40.00/£32.95
doi:10.1017/S0007087418000432

Largely unnoticed by many of us, electroacoustics – the science of translating sounds into electrical signals and back again – permeates our lives through the many and varied applications of microphones and loudspeakers. However, as Roland Wittje points out in the introduction to this detailed and meticulously researched study, it is a subject that has received scant attention previously in the history of science, being largely treated as the story of the technologies involved (see, for example, Frederick Vinton Hunt's *Electroacoustics* (1954) or Emily Thompson's *Soundscape of Modernity* (2002)). Wittje attributes this relative neglect to the ambiguous position of electroacoustics and, more broadly, acoustics itself, which is often perceived as falling between science and engineering, and between pure and applied science. He seeks to redress this by situating acoustics within a broader history of science, expanding beyond the normative idea-focused view of early twentieth-century physics, to privilege practice and application, and thus to connect the history of physics to histories of technology, to cultural histories of sound and to sound studies.

Wittje promotes acoustics as neither a trivial topic nor a dull application of physics through a detailed account of the development of electroacoustics in Germany, from the work of Helmholtz, through militarization during the First World War and demilitarization in the Weimar Republic, to the beginning of the Third Reich and remilitarization, and in so doing draws on a rich body of important German-language sources and archives. He highlights the place of electroacoustics as an ideal instantiation of 'German physics', since it was seen by the National Socialists as a practical, applied science, with very useful applications, especially as

part of the apparatus of propaganda – and hence very separate from the perceived worst excesses of 'Jewish science', such as quantum mechanics or relativity.

During the period of this book – the late nineteenth century to the late 1930s – acoustics changed from being a bourgeois science for the elite, focusing on the interaction between classical music and the trained, aesthetic ear, to a technical discipline informed by electrical engineering: from concert hall and drawing room to factory floor and theatre of war (though we might wonder how successfully this elitism has been eradicated when we consider the supremely precise acoustic design of some classical venues such as Birmingham Symphony Hall, for example, versus the 'warehouse' aesthetic of many popular arena venues). This, therefore, is a story of electrification and industrialization, whereby the arbitration of sound moves from the musically trained human ear, via the 'normal' human ear as defined in Harvey Fletcher's work at Bell Laboratories in the 1920s, to electronic measurement and meters (which connects in interesting ways with Marc Perlman's classic article 'Golden ears and meter readers: the contest for epistemic authority in audiophilia' (*Social Studies of Science* (2004) 34(5), pp. 783–807).

Wittje further compellingly argues that this period also ushers in a change in understandings of sound and of noise, and that electroacoustics brings a new 'conceptual definition of sound' (p. 19). Sound segues from that which is aesthetically desirable to that which is practically necessary, i.e. the signal, while noise ceases to be a culturally defined subjective phenomenon and becomes a measurable distortion of that signal. The First World War was a crucial driver of this change, creating as it did new kinds of sound to be studied and a more urgent need to detect and analyse those sounds. However, Wittje is careful to emphasize that the electrification of acoustics originates well before this; the key drivers and consumers of acoustic research were telephony, radio and film sound, all of which were all well under way before 1914.

The expanding needs of the communication and media industries meant that, by the 1930s, acoustics had become a global activity. Furthermore, as the sound of modernity became louder and more urgent, with increasing industry, traffic and sound-based media, problems of noise measurement and control needed to be addressed, which further cemented the status of acoustics.

Wittje takes a novel approach to the concept of noise, aided by precise distinctions in the German language, arguing that there are three key developments affecting our concept of noise. First, the advent and nature of the First World War meant that acoustics turned away from a focus on the sound of music to attend to the noise of war. Second, growth in media technologies, especially telephony, radio and film, necessitated an electrical turn in acoustics. Finally, the rise of comparative musicology, together with the growth of mass culture, broadened musical thinking to encompass a range of sounds beyond the realm of classical Western music (pp. 190–192).

Wittje argues, convincingly in my view, not only that the received view of acoustics as a branch of engineering or applied science, rather than an element of 'modern physics', is mistaken, but also that acoustics, and especially electroacoustics, was an important ingredient in the transformation of physics in the 1920s and 1930s, offering 'a different vision of what modern physics could be like' (p. 194). The importance of industrial laboratories in physics, such as the role of radio technology and innovation in experimental nuclear physics, has been previously acknowledged and Wittje argues that technical acoustics and electroacoustics led the way in this. Even earlier, acoustics was the gateway to vibrational understandings of physical phenomena, through the 'analogy between acoustics and electromagnetic oscillations' (pp. 190–192). Rayleigh's theory of sound played an important part in Maxwellian electrodynamics and acoustic wave theory remained pertinent to the development of quantum mechanics and relativity.

This detailed, meticulously researched and well-illustrated book is a welcome addition to the growing, multidisciplinary body of literature which takes issues of sound seriously. Wittje concludes with a brief comment on the significant ways in which digital technologies have changed

our understandings of sound (p. 213), but the movement of sound waves in air will always remain a defining characteristic of electroacoustics, as long as there are ears to hear.

Annie Jamieson
National Science and Media Museum, Bradford

Friedrich Steinle, **Exploratory Experiments: Ampère, Faraday and the Origins of Electrodynamics**. Translated by Alex Levine. Pittsburgh, PA: University of Pittsburgh Press, 2016. Pp. 494. ISBN 978-0-8229-4450-8. $65.00 (hardcover).
doi:10.1017/S0007087418000444

Exploratory Experiments is a book that is long overdue, being a translation of Friedrich Steinle's 2005 *Explorative Experimente*. The original represented the culmination of the reaction in the 1980s and 1990s against the theoretical certainties and strongly explanatory models of previous decades, a reaction that saw the rise of microhistory among historians and a 'turn to practice' in the history and philosophy of science. Steinle's reaction was against the view that the only experiments that are of interest to philosophy are hypothetico-deductive tests of theory. Picking up on ideas put forward in the early 1990s by David Gooding and Ian Hacking, Steinle's main aim was to explore the epistemic processes of 'exploratory experiments' – experiments that take place in a context where either there is no underpinning theory, or the underpinning theory is itself at issue.

Such an event occurred in 1820, when Ørsted's discovery of an interaction between electricity and magnetism – an interaction that could not be accommodated in the conceptual framework of central forces with which natural philosophy at the time was steeped – threw the scientific world into turmoil. In the few months of frenzied work that followed, two outsiders emerged as leaders in the new field of electromagnetism: André-Marie Ampère and Michael Faraday. Detailed case studies of the working scientific practices of these two form the core of Steinle's book. They are carefully chosen, not only for their subsequent status as leaders, but for the contrasting cultural, institutional and intellectual contexts within which they were working, and for the availability of rich collections of sources. Comparisons between the two cases allow Steinle to identify commonalities as well as locally situated differences, and to suggest characteristics of exploratory experiments that clearly distinguish them as rational and more methodical than mindless fumbling.

After a brief introduction outlining his situation, aims and methodology, Steinle plunges into an account of the state of knowledge and scientific cultures across Europe in the early nineteenth century, focusing particularly on the locales important for the rest of the book: Paris and London. This is no summary overview; in line with his emphasis throughout on the agency of individuals, he aims to 'capture the perspective of actors … from street level' (p. 11). With the stage thus set, Steinle describes Ørsted's discovery of electromagnetic action, and the furore it raised across Europe. This is one of the few chapters in which he looks more widely than London and Paris, identifying three features of the reaction that appear common everywhere: surprise and attempts to replicate; replication always confirmed the unusual and conceptually unsettling features of the effect. Chapters 3 and 4 are devoted to Ampère's scientific practice. The split corresponds to the two phases that Steinle has identified in Ampère's work: the first three weeks during which he formed concepts and sketched a research programme, and the following four months as he fleshed out that programme, fended off challenges from Jean-Baptiste Biot and Félix Savart, and managed his public image. Turning to London, Chapter 5 identifies systematic differences in the British and French responses to Ørsted, characteristic of the different milieu, and looks at the work of those who formed the backdrop to Faraday's work – especially that of his mentor, Humphry Davy. The chapter finishes with an account of the circumstances surrounding