

INTRODUCTION: TOOLS IN MATERIALS RESEARCH

JOSEPH D. MARTIN and CYRUS C. M. MODY

The science of materials has contributed to changes in our civilization as pervasive as they are profound. The ways we travel, communicate, wage war, build buildings, dress, heal, play sports, read, listen to music, use energy, and care for the young, the old, and the vulnerable have all been shaped and reshaped by our knowledge and mastery of metals, semiconductors, organic and biocompatible materials, gels, plastics, polymers, plasmas, and other substances. But our large-scale historical understanding of materials research is still surprisingly flimsy. We might say of materials research, as common as it is, what Clifford Geertz said of common sense: “it lies so artlessly before our eyes it is almost impossible to see.”(4 p92)

The WSPC Encyclopedia of the Development and History of Materials Science aims to make materials—which we might otherwise overlook for their familiarity—more visible by charting their history. This volume focuses on the tools and practices that have guided materials research. Where did they come from and how were they enrolled in the cause of understanding, manipulating, and fabricating the stuff of the modern world? Laboratories dedicated to studying materials proliferated in the mid- to late twentieth century. They were sponsored by government and military organizations, assembled within universities, and established by industrial firms. And they succeeded in reforming our understanding of matter and changing the material profile of our technological world because a diverse assortment of tools was successfully coordinated within them.

Imagine walking into one of these labs—at Cornell University, or the Centre National de la Recherche Scientifique, or General Electric—in the 1970s or 1980s and looking around. You are surrounded by a wide assortment of tools. Some—glass flasks and beakers, thermometers, microscopes—have been shaped by centuries of development and modification. Others, particularly those taking advantage of various scattering and diffraction phenomena, are recent developments. Still others are so unassuming that you might not register them as tools at all, from the trade catalogues that researchers use to browse new prefabricated materials and equipment, all the way up to the building itself, which was designed to instrumentalize the interactions of the researchers within it. This volume tells their stories.

What Is Materials Research?

A volume of this nature must wrestle with the question of what counts as materials research. Using materials constitutes one of humanity’s oldest technological enterprises. If we wanted to be truly expansive, we could point out that successful flint knapping re-

quires a remarkable sensitivity to the material properties of some types of stone (if not a theoretical knowledge of its structure). And so, from one standpoint, materials research can refer to traditions that are many millennia old and span several radical shifts in craft and scientific understanding of the stuff that makes up our technologies.

From another standpoint, however, materials research is a much more recent enterprise. Fields that trade principally in material properties, such as metallurgy or inorganic chemistry, can boast centuries-old research traditions. Only after World War II, however, did institutions and communities emerge that were dedicated to systematically applying physical and chemical understanding of solids to the characterization, manipulation, and synthesis of materials in service of human ends.⁽¹⁾ When we speak of “materials science” or “materials research” today, we usually mean this tradition of much more recent vintage.

Some tools are better captured by the more expansive definition of materials research, others by the narrower, contemporary perspective. Rather than imposing a particular view of materials research on this volume as a whole, we have left the decision about how to understand the scope of materials research largely up to individual contributors—different understandings of the field are better suited to telling the stories of different tools. This volume, therefore, is not just a catalogue of the histories of individual tools; it is a study of how those tools have helped to define the boundaries of the field. We believe this approach reflects the reality that the precise parameters of materials research are difficult to establish, especially in historical inquiry. Rather than presenting a narrow vision of what materials research is, we hope the following essays will inspire you to ask yourself what we can gain by considering these tools, many of which have long histories and diverse applications, as part of the story of materials research.

Themes and Patterns

One of the joys of assembling a multi-author work such as this one is to watch how diverse perspectives combine to illustrate larger themes and pattern that might not have been evident to one or two authors on their own. In reading the contributions that follow, we have noticed a few such themes and patterns that bear emphasizing—although we also encourage readers to be attentive to those that we don’t highlight here.

First, we note the rising prominence of the black box. The entries in part 1 frequently reference experimenters who are also toolmakers. Chemical analysts and synthesists were often also glassblowers, as Catherine Jackson discusses. Critical advances in thermometry were made by the people interested in studying the phenomena of heat, as we learn from John Powers. These early tools were usually bespoke, designed for particular and often narrow tasks. As we move into the middle twentieth century, however, we begin to see more and more tools coming in standard form, designed to be used in standardized ways and to free experimenters from the tasks of instrument design.

This is not to say, however, that the black-boxing of instruments reduced the importance of tacit experimental sense. We only need to read Cyrille Foasso’s entry on information display and recording to see how even standardized instruments require the same subtle sensibility that might have informed an expert chemist-*cum*-glassblower in

the mid-1800s. Following the theme of black-boxing instruments therefore indicates both a discontinuity and a continuity. It shows a growing division of labor between tool makers and tool users, but it also represent a continuity of the sorts of skills and sensibilities required to approach the science of materials.

Second, we discern an increasing internationalism in the practice of materials research. This is little surprise, insofar as it mirrors the extent to which most of science and technology became more international over the span of the twentieth century. But it is notable that materials research followed a similar trajectory given the extent to which it is and has been bound up in national and commercial interests. Tools for materials research were emerging from international collaborations and moving across borders even as they were being directed toward classified military research and being subjected to intellectual property regimes, and their stories have much to tell us about the ways in which those regimes of secrecy and control shaped the internationalization of science and technology.

The third theme we discern is an arc that describes the types of materials at which tools tended to be directed. Through the twentieth century, this arc moved from regular crystals and molecules to amorphous solids to squishy biomaterials. A technique like X-ray diffraction, as Robin Scheffler notes in part 4, was seen as ideal early in the twentieth century for studying the regular crystal structure of solids, and molecules with repeating structures like protein and DNA. Later in the century, tools like nuclear magnetic resonance spectroscopy provided the different variety of data that was necessary to tackle the somewhat different challenge presented by amorphous materials and organic matter. The story of tools in materials research, that is, was not just a story of new instruments and techniques opening up new vistas. The materials themselves pushed back. Evolving notions about what constituted a useful material influenced what sorts of tools gained prominence, and what developmental trajectories those tools would take.

Finally, we note that we have imposed a somewhat artificial distinction on this volume between tools for making materials (part 3) and tools for characterizing materials (part 4). Many of the tools discussed in these final two section straddled that boundary, or had distinct applications for manufacturing materials and exploring their properties. The artificiality of that distinction indicates the ways in which materials research challenges some of the distinctions that, for better or worse, have shaped much of our thinking about science and technology in the twentieth century—in particular between basic and applied research. It is *de rigueur* for today's historians to observe that this distinction is artificial and does not appear so sharply in scientists' practice as we see it expressed in their rhetoric. What we see in the contributions to this volume, however, is the value of further attention to those fields where the distinction was not only moot, but was not even a rhetorical advantage.

How to Use This Book

The short essays that follow each introduce a few essential historical features of the instruments, techniques, and practices that make up materials research. These tools have rich and intricate histories, which cannot be done justice in just a few pages. These essays, do, however, show us why the stories of these tools matter. You can use them to

learn how particular tools fit into some of the larger stories of the history of science and technology and to find guidance for more in-depth study. We hope that this volume can be comprehensive in one, limited sense. It will not tell you everything that's worth knowing about thermometers, or lasers, or mass spectrometers. But by discussing how all of these tools, and many others, contributed to some of the most important developments in the history of science and technology, this volume provides the most inclusive historical compendium to date on the techniques people have used to pursue their fascination with materials and their uses.

We have sorted the tools of materials research into four categories. The first, "Always Already Tools," describes apparatus that all materials researchers must master as part of basic laboratory procedure. Scales and balances, glassware, thermometers, microscopes, and other such tools have long histories and are likely familiar to secondary school chemistry students around the world. They are also relevant to every stage of the research process and every type of materials research. Metallurgists fabricating new alloys and biomedical scientist designing novel implants will need precision weighing devices just as much as the basic physical or chemical researcher interested in a substance's essential properties. These humble tools thereby have tremendous influence over the practice of materials research.

Part two, "Invisible and Infrastructural Tools," confronts those tools that are necessary before research can get off the ground. These include the buildings and trade catalogues mentioned above, as well as safety equipment, clean rooms, information display and recording devices, and standards, to name a few more. These tools and procedures, although they rarely arise when we think about how we research materials, are far from ancillary. They are critical both to the process of investigation and to the social relations that make it possible.

"Tools for Making Materials" are the subject of part 3. It is easy to take for granted that the things we use to navigate the world have properties suited for the tasks to which we turn them. But the precision and consistency of those properties more often than not depends on the mastery of some delicate laboratory procedures. Tools like lithographs, centrifuges, distillation columns, and specialized heating and cooling devices have developed to ensure that we can shape the properties of materials to meet specific demands, and that those materials will perform predictably and reliably in our technologies.

Finally, part 4 addresses "Tools for Characterizing Materials." The better understanding that emerged through the twentieth century of various types of radiation, of the micro structure of matter, and of how these two interact, paved the way for a variety of new, non-destructive techniques for investigating the structure and properties of materials. Investigations of the properties of materials have advanced our basic understanding of matter. They also allow us to manipulate it more easily. The story of these tools is the story of how abstract knowledge and practical know-how can proceed in lockstep.

Each of these sections begins with an introduction that provides general background for the essays that follow. Whereas the shorter essays focus on particular tools, these longer introductory essays offer readers a wider-angle view of the types of tools investigated in each part. They discuss existing historical work in more depth and comment on the big historical questions that the histories of these tools raise. These essays provide

essential context for the shorter vignettes they introduce and prompt readers to understand the often-detailed history of particular tools within the larger sweep of the histories of science and technology.

Situating the Volume

Readers will note that each of the volume's four sections is longer than the previous section. This is *not* a reflection of the editor's valuation of these four topics. We see all four categories of tools as equally important for understanding the historical evolution of materials research. Rather, the greater weight accorded to synthesis and characterization tools reflects the current breadth of scholarly interest in those topics. Significantly more studies thus far have scrutinized high-tech instruments and techniques used in materials science, condensed matter physics, colloid and polymer chemistry, and related fields than have examined ancient or infrastructural tools used in those same disciplines. Of course, a ancient alchemical glassware and other older experimental equipment do have literature devoted to them(7)—but few studies connect those techniques to modern materials research. Similarly, quite a bit has been written about some kinds of infrastructural tools—for example, laboratory buildings(3,5)—but, again, not specifically linked to the history of materials research. One aim of this volume, therefore, is to bring greater attention to the role of these kinds of tools in materials research and to encourage our colleagues to incorporate their histories into general narratives of the field's development.

The reasons this has not yet happened already are many. One is that materials research, as such, is only about a half-century old. It is perhaps more surprising that there are any historians of materials research at all than that some corners of that history have not attracted scholars. The more developed topics—histories of individual instruments or techniques—are good targets for PhD dissertations, so many of the extant studies grew out of thesis topics.(11,12) A modern instrument or technique usually comes with an easily identifiable published literature and often with a dedicated community that is willing to be interviewed or that even generates its own first draft of its history. By contrast, studies that span the centuries- or even millennia-long development of ancient tools that live on in materials research require a depth of expertise that PhD students would be challenged to develop. Similarly, infrastructural tools are associated with historical sources that are difficult to come by and therefore risky for a PhD student to investigate.

We could also point to a number of what one of us (Martin) has call “prestige asymmetries” that explain why histories of instruments and techniques for materials synthesis and characterization are more prevalent than histories of older and infrastructural tools.(8) High-tech instrument-making is strongly associated with disciplines—especially physics—that long dominated the history of science. Histories of large instruments designed for the physical sciences, such as telescopes and particle accelerators,(9,6) were common up to the beginning of the present century. Histories of smaller-scale condensed matter physics instruments were less abundant; but because many of these instruments were linked to a Nobel Prize in Physics, most historians of physics recognized histories of these instruments as integral to their field. Ancient and infrastructural tools, by contrast, rarely merited Nobel Prizes in anything. Histories of such tools would be harder to

justify, at least in the eyes of other historians, and would therefore be riskier, especially for PhD students and early career scholars.

But why would there be fewer Nobel Prizes for ancient and infrastructural tools? The question perhaps answers itself, but it also reveals important dynamics, both in history and in science, that this volume attempts to contest. One dynamic is the asymmetric prestige accorded to technological innovation as opposed to maintenance, adaptation, conservation, and simple enduring use, at least in the global north.⁽²⁾ New technologies, and especially new research technologies, are seen as contributing more to economic and social life than old ones, even if all indications are that the old technologies dominate both the laboratory and ordinary life. Hermione Giffard's introduction to part 1 elaborates on this point.

Another related dynamic is that new characterization and synthesis tools often are—or are often seen as—the creations of celebrated geniuses who just happen to be middle-class men, whereas ancient and infrastructural tools have a long association with women, the working class, and other subalterns. One aim of this volume is therefore to highlight the ubiquity and centrality of collective effort in the development of all the tools used in materials research, including characterization and synthesis tools. Nobel Prizes might go to groups of no more than three, but historians' narratives should reflect a more distributed process of design, use, and refinement. A second aim of this volume is to connect the history of materials research to labor history, and in particular to the labor history of groups whose members rarely win Nobel Prizes. Entries that could be grouped under this theme include (but are not limited to) those by Justin Carone (mechanical testing), Amy Slaton (safety), Julia Bursten (computing and simulation), Debra Kolah (bibliographical tools), Joanna Behrman (recipes and manuals), and Catherine Jackson (glassware).

It has not escaped the editors' notice that this theme should also apply reflexively to this volume itself. We believe that socially responsible materials research must be inclusive and therefore requires a diverse group of practitioners.⁽¹³⁾ We also believe that the entries in this volume demonstrate that there has been greater diversity in the history of materials research than many of its practitioners (and historians!) acknowledge, and that that diversity has given rise to epistemically more robust knowledge of materials. The same should be true of histories of materials research, and we have therefore tried to recruit a diverse group of authors. Readers will find a few well-established authors, such as Catherine Westfall and Christophe Lécuyer, who have been writing on this topic for much of their careers. Their voices are joined by scholars, such as Brit Shields and Jorijn van Duijn, who have entered the historical profession more recently.

We also sought essays by practicing materials researchers, such as Philip Wankat and Gerald Gallwas, as well as practitioners-turned-historians such as Catherine Jackson and dual practitioner-philosophers like Thomas Vogt. As mentioned above, practitioners usually (and rightly) write the first histories of the tools their communities have developed. Those participant histories offer a compelling firsthand account of developments. But immediacy is not the only reason why practitioners must be part of writing the history of materials research. Another is that good history of science must grapple with arcane technical detail. Researchers are not human beings in one corner and technical experts in another; they are always both together, and crafting a historical narrative requires contin-

ual melding of the two. It is no coincidence that a substantial number of our authors, including one of us (Mody), have at least one degree in a field related to materials research. That is not a prerequisite, of course. Two people cited throughout this volume, Ann Johnson and David Brock, developed their deep understanding of materials science after becoming historians, as did many of the authors included in the volume. Again, we aimed for a diverse group of authors because we believed that would lead to a more comprehensive and robust understanding.

One place where we, as editors, failed in that aim is in making the history of tools in materials research a global story. Only two of our essays, by Victoria Lee and Indianara Lima Silva, devote much attention to places outside of Europe and North America. That is partly a reflection of inadequate effort and imagination on our part, as well as a reflection of the time required to write even a short historical essay with global, or even transnational reach. It is also a reflection of a real gap in the literature. If prestige asymmetries have led to greater emphasis on the histories of some instruments more than others, they have also led to greater emphasis on the history of instrument development in some places more than others. We do not, however, believe that the geographic narrowness of this volume in any way reflects the reality of instrument development. As Amit Prasad argues, any topic of research is always already global, that is, sustained by networks with participants from all over the world.⁽¹⁰⁾ It is therefore never possible to say that the development of a particular tool “started in” one place or another. Over time, global economic and political power asymmetries mean that some nodes in those networks come to be seen as more central than others, and some nodes therefore drop out of historical memory. In Prasad’s case study of magnetic resonance imaging, the ironic result was that many Indian MRI researchers believed that the technique was invented in the United States and United Kingdom and were unaware of its deep history in India itself! Much the same could no doubt be shown for many of the tools represented here, and our hope would be that further research will correct this volume’s shortcomings in that respect.

In closing, we should note that examining materials research through tools is just one way to access its history. This book is part of a series that explores some other approaches in parallel. We encourage you to consider the history of materials research through the lenses of the institutions that supported it, the markets that drove its development, and the materials themselves. Together, we hope that these volumes can map out an agenda for further historical work into a field that has made countless contributions to our scientific understanding of the world, and whose technological developments pervade our lives, but whose history we have only begun to systematically explore.

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