

THE  
**SHAPE**  
OF  
**SPECTATORSHIP**

ART, SCIENCE,  
AND EARLY CINEMA  
IN GERMANY

SCOTT CURTIS

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# 1

## SCIENCE'S CINEMATIC METHOD

### MOTION PICTURES AND SCIENTIFIC RESEARCH

*Time would flee, I subdue it.*

—CHARLES CROS (1877)<sup>1</sup>

In the early 1890s, after Étienne-Jules Marey's successes with chronophotography ensured the continued viability of his "graphic method" of recording motion,<sup>2</sup> two German physiologists, Wilhelm Braune and Otto Fischer, set out to improve upon Marey's techniques for the study of human locomotion. No mere dilettantes, Braune and Fischer were already well known in their field for studies of the human center of gravity and other investigations into the fundamentals of human motion. From 1889 to 1904 they published a series of studies of human locomotion, culminating in their landmark work, *Der Gang des Menschen* (The Human Gait).<sup>3</sup> In their Leipzig laboratory, they dressed their experimental subject, a military recruit, in a black jersey and attached to him an elaborate mechanical scaffolding of incandescent tubes designed to illuminate his stride with short, intensely bright bursts of light (fig. 1.1). They then photographed the subject as he walked, as comfortably as could be expected, across the darkened room. As he walked, the tubes fired, producing a strobe effect that was recorded through the camera's open shutter. The resulting image—a series of white lines across a black background—became the basis for hundreds

of calculations concerning the specific mechanics of human motion (fig. 1.4). Interested in the economy of the laboring body—its most efficient conservation and expenditure of energy—they hoped their scientific analysis of human movement would lead eventually to a more efficient and productive society (or, at least, a more efficient soldier). Likewise, their improvements over Marey's system of photographic measurement led to a much more analyzable and therefore "productive" chronophotographic image. After Braune and Fischer, photographs became even more efficient and productive tools of scientific research.

In Marburg in 1907, a young physicist named Max Seddig presented his dissertation on "Measurement of the Temperature Dependency of Brownian Motion."<sup>4</sup> In an attempt to clarify the arguments for and against the atomic-kinetic model of heat, while also trying to provide experimental confirmation of Albert Einstein's theories of Brownian motion, Seddig fashioned a device that could record chronophotographic images of microscopic particles affected by molecular activity. Seddig's microscope-cinematograph combination supplied an objective record of Brownian motion from which he could calculate the velocity of these particles. Yet it was not the objective record that Seddig emphasized and praised but the machine's ability to measure time intervals precisely. Alternatively, Heidelberg biologist Hermann Braus presented in 1911 the results of his application of a similar microscope-cinematograph combination to record and explore the growth of a tissue culture of a frog's heart.<sup>5</sup> Using time-lapse cinematography, Braus sought to demonstrate that the culture actually grew rather than merely survived outside the organism. Unlike Seddig, he was not so concerned with measurement but with the temporal record of the event. With his motion picture record Braus was able to challenge competing claims about the growth of nerve cells.

These three cases—from human motion studies, physics, and biology, respectively—represent a fair sampling of the scientific use of film for research purposes in Germany before 1914. From these case studies we can draw some preliminary conclusions about the practical and philosophical connections between film and science. We might also be tempted, of course, to make general theoretical claims about the nature of cinema's relationship to modern science and temporality.<sup>6</sup> But if we are to understand film's role in modern scientific inquiry, we must temper expansive claims with more historically localized analyses of how film technology was actually *used*.<sup>7</sup> What "film" meant to any given scientist depended very little on a theoretical conception of cinema in general; instead it depended primarily on how

some specific incarnations of motion picture technology could be applied to the specific and historically contingent problems the scientist faced in his or her discipline. Hence any study of scientific research films must incorporate methods common to both the history of science and film history by investigating the manner in which research questions and media technology mutually influenced each other. What questions does a given discipline privilege at a given time? How do those questions shape—indeed, how are they shaped by—experimental design and available instruments? The appropriation of motion picture technology as a scientific research tool, its specific use within the laboratory, reveals the researcher's assumptions about that which the camera is designed to capture. And these assumptions vary as widely as the different uses of film. But rather than making broad claims about what “science” or “cinema” is, thereby concealing this variety under top-down theoretical categories, we should let individual experiments reveal their assumptions and make our generalizations from those, if necessary. Design and deployment are themselves implicit theoretical statements.

If the cinematograph were an especially flexible tool that could be adapted to a number of different needs, these needs existed in the first place because of changes in the sciences themselves at the turn of the century. Biologists interested in cell development, for example, searched for new modes of visualization that would allow researchers a clear view of movement in time to resolve some heated disputes about the nature of cell growth; the techniques of tissue culture, on one hand, and those of motion pictures, on the other, offered two kinds of solutions, as we shall see. Physicists, too, looked to cinematography as a tool for investigating previously invisible phenomena, such as the effects of molecular movement, a topic of debates about the behavior of atomic phenomena. Seddig's use of chronophotography and motion pictures reflects a common application of this technology in scientific research; while scientists admired cinematography's ability to capture fleeting phenomena, they prized most highly film's ability to decompose the event into discrete, regular units, which permitted measurement of its temporal and spatial components. Indeed, this particular use of motion picture technology, especially in the physical sciences, betrays an assumption about the event or phenomenon under study as itself discrete, divisible, determined by classical laws, regular, and—just like the filmstrip—reversible. Seddig's use of motion pictures therefore demonstrates at once the value of film for scientific research and his (and Einstein's) commitment to a particular understanding of the relationships between movement, time, and space—an understanding that French philosopher Henri Bergson was

criticizing at precisely this moment in *Creative Evolution*, his 1907 landmark study of the philosophy of biology. In short, as scientific disciplines reconceptualized the nature of matter, time, space, and the organism, they seized upon tools that could visualize these phenomena in accordance with these new concepts.

But film has never been just a convenient device, patiently waiting on the shelf as the scientist thinks up a new use for it as a solution to a new problem. Its availability and its existence also generated questions. Investigators' interest in temporal phenomena was in part spurred by the arrival of a machine that could make the phenomena amenable for analysis. Furthermore, those scientific research programs that featured film technology were not only shaped by that technology, but their scientific method itself had certain features in common with the filmic apparatus. Scientific experiment shares with motion pictures an impulse to record immediately and directly, a willingness to manipulate time, and an inclination to isolate and quantify phenomena.<sup>8</sup> There are good practical reasons for using motion picture technology, of course. But in the late nineteenth century there developed also a *philosophical* affinity between science and film that went beyond mere convenience. Cinema and science have come to share a certain way of thinking, so the history of the application of motion pictures in science can offer us a valuable opportunity to explore the relationship between science and modernity. Bergson was the first to suggest that science, through its parsing of continuous movement into discontinuous moments, proceeds in a way analogous to cinematography. If we are to understand fully the implications of the appropriation of motion picture technology by the scientific community, we must maintain a balance between the theoretical and the practical by considering this philosophical affinity alongside the way investigators put film to work in the laboratory. Bergson's conception of science as inherently "cinematic" offers us a logical point of departure for such considerations. True enough, Bergson was not as popular in Germany as he was in France and the United States. But because I am interested in his thoughts on cinema and science in general—and not in his thoughts (if any) on particular applications in Germany or elsewhere—his historical impact on German culture is actually not relevant to my approach. Bergson's theoretical framework can help us answer the question "What did cinema and science see in each other at this particular moment?" The individual case studies can reveal *how* film was used; reading Bergson alongside these cases can help to reveal *why* film was used. This chapter, then, will survey the use of motion pictures in the three case studies mentioned above.



Let me first reiterate the role of this chapter in the book's overall goals. As I mentioned in the introduction, the larger argument (the "general theory," if I may) concerns the correspondence and mutual accommodation between the logic of a discipline—its problem-solving patterns, its investigatory methods, its ideological assumptions—and film's formal characteristics. This implies not just taking advantage of a medium-specific formal feature, such as temporal malleability (for example, time-lapse cinematography), to solve a representational problem, it also implies a functional or productive homology between this formal feature (for example, the linear regularity of time-lapse recording as a statistical sample of a larger unit of time) and a way of solving problems (the primacy of mathematics, for example) or of viewing the world (as naturally divisible into equal, regular units, for example). This match—between the formal features of the representational technology and the investigatory presumptions—matters, because it provides the researcher, community, or discipline with the reassuring sense that the tool will fit the task to which it is assigned. However, we must note that the match is ideally never perfect; otherwise there would be no new information. Experimental systems are designed to generate new questions, so there should be a dislocation or displacement between the more or less ideological assurance of this tool's "worldview," so to speak, and the strangeness of the view it provides.<sup>9</sup> Time-lapse cinematography can, for example, confirm an understanding of nature as regular and divisible, but it also offers a surprising, even thrilling new image that prompts new questions. The larger argument of this book is that the acceptance of any new (media) technology depends in part on this correspondence between some set of its formal features and the logic of the discipline. The specific argument (the "special theory") is that expert vision expresses this disciplinary logic especially well and that film's legitimacy within disciplines depended on its accommodation to expert modes of viewing.

But expert viewing is not the only way that disciplinary logic is expressed; the experimental system itself is also a manifestation of the discipline's problem-solving patterns and theoretical presumptions. As Gaston Bachelard and others have argued, instruments are "theories materialized": the design and deployment of experimental technology carries a preconception or preunderstanding of the phenomenon it is designed to isolate.<sup>10</sup> If we extend this system to include chronophotography or motion picture technology, we can see how the work of accommodating their formal features already made a statement about the relationship between the system and the object of study. Indeed, the work of creating a legible image—that is,

understandable and acceptable to the discipline—reveals this relationship between system and object quite clearly. Likewise, the theory guiding the experimental observations is an expression of disciplinary logic. If instruments are theories materialized, then, as Hans-Jörg Rheinberger has noted, theories are also “machines idealized.”<sup>11</sup> Einstein’s theory of Brownian motion, for example, made several “shortcuts”—including the presumption of molecular two-dimensionality and velocity without direction, as we shall see—to manage the object mathematically and accommodate the phenomenon to both experimental confirmation and a particular disciplinary understanding of nature. Einstein’s mathematics, in other words, simultaneously became an “instrument” to guide observation *and* a theoretical rendering of the experimental situation. To offer one more example, disciplinary logic can be expressed through the experimental system’s representational options. Film is only one part of an experimental system, of course, and only one in a range of representational tools that includes writings, sketches, graphs, and photographs. Selecting film as part of this media ensemble already implied a certain set of questions or needs. Hermann Braus, for example, found that using film was an especially powerful means of engendering belief among colleagues, while at the same time expressing, through its formal features (such as the duration of the projected image and its temporally forward motion) theoretical presumptions about cell growth. In this case, film and the new technology of tissue culture—also a representational tool—combined to express a new direction in the discipline’s visual needs and strategies.

So the correspondence and accommodation between experimental system or discipline and technology can happen in several ways, depending on the researcher’s or discipline’s goals and needs, which are locally and historically determined. This chapter will explore the “general theory” rather than the “special theory” of media technology’s disciplinary legitimacy. Specifically, this chapter will focus on three ways in which experimental systems incorporated chronophotographic or motion picture technology, especially on the correspondence and mutual accommodation between a given set of formal characteristics (of photography and/or film) and (1) an *object of study*, (2) a *theory*, and (3) the *representational options* of an experimental system and discipline. Or, to put it another way, each of these three adaptations required a certain kind and amount of work to make the chronophotographic or filmic image into evidence. A close analysis of Braune and Fischer’s method will show how they created evidence in relation to their object of study (in this case, the human body). The discussion of

Seddig's experiment stresses the creation of evidence in relation to a theory (Einstein's theory of Brownian motion). And the section on Braus emphasizes the creation of evidence in relation to a set of representational options within a discipline (here, cell biology). Each example deals to some extent with all three adaptations, of course, because they are intertwined, but the emphasis changes. In general, I will demonstrate that while the scientific community readily accepted chronophotography and film as valid instruments, investigators still had to perform considerable labor to adapt these devices to their tasks and to transform the resulting images into acceptable scientific evidence. Motion pictures may have allowed scientists to manage time and movement, but researchers first needed to manage film's temporal rush and excessive detail. The nature of this work was shaped by its historical context. The subject of this chapter is therefore the way that investigators were continuously obliged to adapt as they juggled chronophotographic or motion picture technology, the needs of the individual experiment, the theories shaping the experiment, and the discipline's priorities shaping the representational choices.

While observation is not an explicit focus of this chapter, it is inescapable. Braune and Fischer decomposed movement to train expert vision to phenomena that it might not see or have been able to see. Einstein's theory of Brownian motion focused experimenters' attention, showing them what to look for. For Braus, film was an observational tool that forced researchers to abandon previous theories and modes of analysis (which emphasized discontinuity) for an approach that emphasized synthesis and continuity. These case studies demonstrate that, as Ian Hacking has noted, experiment and observation are only heuristically separable.<sup>12</sup> Nevertheless, this chapter emphasizes other ways, besides observation, that disciplines accommodated the formal features of film and chronophotography. Expert vision is the explicit focus of the following chapters.

The chapter has five sections. It starts with a general overview of scientific research films (as opposed to popular science films) before World War I, in which I outline various prominent applications as well as some hypotheses about how motion pictures fit with the rhetorical goals of scientific enterprise. (A majority of scientific applications of film during the early period were devoted to various medical fields, which I will explore separately in chapter 2.) The next section continues to explore why motion picture technology was intriguing to researchers; it focuses on Bergson's discussion in *Creative Evolution* of the relationship between cinema and science. In the third section, I place Braune and Fischer's work on human

locomotion in the context of both social modernity and the science of work. This section contains a detailed explication of Braune and Fischer's method to show exactly how the merging of apparatus, image, and object actually occurs. The fourth section relates Seddig's work to the general problems of atomistic physics at the turn of the century. In the fifth section, I sketch Braus's cinematic contribution within the context of *fin de siècle* changes in the discipline of cell biology. The concluding paragraphs of this chapter compare the different cases directly to emphasize the mutual dependence between motion picture technology and emerging scientific agendas.

## EARLY SCIENTIFIC FILMMAKING: AN OVERVIEW

Scientists from a wide variety of disciplines—including but not limited to botany, military engineering, meteorology, neurology, psychology, and medicine, as well as the three already mentioned—were among the earliest users of motion picture technology.<sup>13</sup> Most histories of research films start with Jules Janssen, Eadweard Muybridge, and Étienne-Jules Marey, who were important transitional figures between scientific photography and motion pictures.<sup>14</sup> The initial adoption of moving images was relatively smooth because so much work had already gone into creating scientifically valid photographic images during the middle decades of the nineteenth century. The slow process by which still photography had been standardized—setting norms for emulsions, exposure times, preparation techniques, image interpretation, and so on—meant that the enthusiasm for photography often collided with rapidly evolving disciplinary requirements for scientific documentation. As Jennifer Tucker and others have shown, photography was not immediately and unconditionally accepted as a completely objective and scientific record.<sup>15</sup> Photography's evidentiary status depended on its ability to meet several criteria of production and reception. Photographs had to withstand cross-examination by experts from any discipline to which they wished to testify; they were as subject to expert judgment as drawings or other illustrations.<sup>16</sup> In Germany, for example, microphotographs were not generally accepted as proper evidence by the scientific community until respected bacteriologist Robert Koch's innovations and rhetorical efforts made "reading" photographs of bacteria a truly collective activity among an international group of scientists and physicians.<sup>17</sup> Yet by the 1890s, the protocols for generating acceptable scientific photographs had been

established in most disciplines, so the innovation of motion pictures was greeted enthusiastically, their way smoothed by Marey's renowned chronophotographs and graphic inscription methods.<sup>18</sup>

Marey is indeed the most important figure in any history of early scientific film, because his efforts and resources shaped the application of motion pictures to scientific experiment. Marey was intrigued by Muybridge's serial photography when he first encountered it in 1881 but ultimately disappointed in its scientific value: Muybridge's 24-camera, trip-wire method of recording was prone to mechanical inaccuracy and incapable of managing the exact time intervals required for careful research. So at the Collège de France in the 1880s and 1890s Marey explored photographic and chronophotographic methods for visualizations of movement that accounted for distances and times more precisely. The Institut Marey was founded in 1901 to carry on his work; researchers such as Lucien Bull, Pierre Noguès, and Joachim-Léon Carvallo continued to explore the relationship between experiment and visualization, especially in the areas of slow and high-speed cinematography and X-ray cinematography. Marey's assistant at the Collège de France, Charles Émile François-Franck, continued his work on microcinematography in particular; collaborating with Lucienne Chevrotton, Fred Vlès, and others, François-Franck published widely on the chronophotographic and cinematographic recording of microscopic and macroscopic movement. These two sites were also magnets for individual researchers searching for novel ways to make visible their objects of study; French biologist Antoine Pizon and Swiss biologist Julius Ries both worked with the team at the Institut Marey to capture visually the process of cell division, for example, while François-Franck helped French physicist Victor Henri with his research into Brownian motion (I will have more to say about all of these examples later in the chapter).

Whether scientific cinema grew out of team efforts focusing on new visualization techniques or out of the work of individual researchers focused on experimental problems that motion pictures might solve, both models had one thing in common: the need for resources. Needless to say, the early motion picture apparatus was expensive, often cumbersome, and usually difficult to adapt. Its use in scientific circles, therefore, was generally restricted to established researchers who had the necessary financial and technical resources at their disposal. Indeed, the distribution of resources largely dictated the spread of motion picture technology in the laboratory. Thanks to Marey's considerable political and scientific skill, France could boast at least two sites with the necessary budget and expertise to pursue

such a program. Germany also had a university research infrastructure in place that allowed individual researchers to explore the use of motion picture technology, but no single site dominated.<sup>19</sup> Aside from the many medical applications, which we will examine closely in the next chapter, we can count botanist Wilhelm Pfeffer's time-lapse chronophotography of plant growth at Leipzig University and Carl Cranz's high-speed studies of ballistics at the military academy in Berlin-Charlottenburg as notable intersections of science and film at the university level.<sup>20</sup>

Research film also received a boost from manufacturers who recognized that lending their equipment and funds provided not only a measure of legitimacy and good press but entertainment for movie-going audiences as well. Pathé Frères, for example, funded the filmmaking of microcinematographer Jean Comandon and then distributed his films to theaters around the world.<sup>21</sup> Occasionally a German manufacturer would lend a hand to researchers; film pioneer Oskar Messter, for example, had pretensions in this arena, and companies such as Ernemann were sometimes acknowledged as technical patrons.<sup>22</sup> But even researchers who purchased the basic apparatus from a manufacturer such as Lumière or Ernemann were still obliged to make modifications to the equipment in their own laboratory setting. Carl Zeiss's optical laboratory in Jena, for example, seems to have been especially suited to this kind of work. Generally speaking, despite the involvement of some film manufacturers, these films were usually made by specialists to be shown to other specialists at scientific conferences or in the lecture hall.

This is not to say, however, that scientific films were limited exclusively to an elite audience. Scientific titles were often part of the program at the local movie theater. Companies such as Pathé, Gaumont, and Éclair in France or Urban in England, especially, produced their own series of scientific films for general audiences.<sup>23</sup> German audiences would have been familiar with this genre from the titles imported by these companies. (Foreign manufacturers generally dominated the German exhibition market until the 1910s.) In addition, the German periodical *Film und Lichtbild* (a German *Popular Science* for film enthusiasts) acted as something of a clearinghouse and ad hoc distribution company by publishing lists of scientific films and offering discounts to its readers.<sup>24</sup> There were also dedicated screenings occasionally,<sup>25</sup> as well as theaters devoted to the genre, such as the Fata Morgana theater in Dresden, which opened in August 1912 and showed only scientific, industrial, and nonfiction films.<sup>26</sup>

But what of the research films of a Seddig or a Braus? Did they ever find their way to the public? It is very difficult to say without a complete survey and correlation of all films made in the laboratory with those screened in public or semipublic venues—a task that is likely impossible to complete. There are good reasons for both possible answers, yes and no. On one hand, these films were the result of considerable expense and effort, so investigators might have been reluctant to give them up for duplication.<sup>27</sup> (Comandon and others like him were exceptions, because they made legitimate research films for hire.) Also, some scientists might have hesitated to cross the line between serious research and its popularization. Motion pictures already had acquired the yellow tinge of mass culture, so some investigators were probably reluctant to have their work completely jaundiced by a matinee showing at the local nickelodeon. Not that the scientific application of motion pictures encountered serious objection; while film histories often repeat legends of academic hostility to researchers using motion pictures in their experiments (usually limited to French medical films and the Doyen controversy, described in chapter 2), evidence of such protests is actually rare in comparison with the general enthusiasm displayed for the new technology. On the other hand, research films were the topic of a considerable number of screenings and discussions, and teachers, reformers, and even scientists encouraged these ventures into the popular realm as important efforts at public outreach.<sup>28</sup> Furthermore, there were already a number of screenings of these films in the semipublic realm of the university lecture, so it would not have been too much of a leap to take the next step.<sup>29</sup> And as manufacturers such as Messter and Ernemann lent their equipment and expertise to researchers, they may have asked for copies of the films, which might have been made available for rental in the manufacturer's catalog.<sup>30</sup> It seems that the public screening of any given laboratory film depended on the resources and predilections of the individual researcher or the manufacturer; I have not yet found a consistent conduit in Germany between the scientific laboratory and the movie theater.

By and large, then, these films served primarily as a form of scientific evidence. Despite its mass culture connotations, its high cost, the high level of technical expertise required, and the often futile results, motion picture technology offered several tempting benefits to the researcher. Like still photography, the motion picture camera provided a mechanical, automatic, hence “objective” record, thereby adding substantial evidentiary weight to scientific claims.<sup>31</sup> The photographic image, like other graphic inscription

devices (such as the electrocardiograph), seemed to provide researchers with an unmediated and permanent record of any given phenomenon, one that could be stored and disseminated with ease. And because it could be projected and reproduced, the photographic image proved useful for demonstrations as well as experiments; indeed, a motion picture projector was just as likely to be found in a lecture hall as in a laboratory.<sup>32</sup>

Unlike still photography, however, the motion picture had the capacity to record events as they occurred over time. This singular feature offered several advantages. The camera itself could act as a mechanical, indefatigable prosthesis of the scientist's eye, a tireless observer of events that was able to catch the slightest change without the interruption of a blink. Furthermore, motion pictures offered the scientist the option of manipulating time by recording (or projecting) the film at different speeds. Slow-moving events could be sped up with time-lapse techniques; fast-moving phenomena could be slowed down through high-speed cinematography. As a result, temporal events invisible to our ordinary perception became "visible"; film became a kind of temporal microscope or telescope, bringing nature's aloof wonders closer to our level. Finally, as implied above, the motion picture camera could also act as a precise measuring tool. By controlling the rate at which the film passed through the camera as the phenomenon traveled a set distance, the scientist could then calculate the speed of the recorded movement. This ability was by far the most intriguing aspect of cinema's scientific potential, and researchers spent considerable energy perfecting it.

Motion picture technology, then, was an especially flexible tool that could be adapted to a number of different tasks. In this respect, however, it is no different than any number of technical innovations adapted for scientific use, from perspective drawing to the computer. Successful adaptation depends on a variety of circumstances, but as sociologist of science Bruno Latour has argued, the most salient predictor of which technologies the scientific community will adopt is the extent to which the adoption will aid the community in rhetorical struggles. Latour maintains that technologies that serve as inscription devices, or "writing and imaging procedures," function rhetorically in debates between authors and groups as tools that help "in the mustering, the presentation, the increase, the effective alignment, or ensuring the fidelity of new allies."<sup>33</sup> Struggles between scientists are the same as those between generals and politicians, Latour argues; those with the most allies win. Therefore, the essential characteristics of any inscription device—the qualities that will ensure its success in the scientific



arena—have less to do with its ability to provide accurate inscription (visualization, writing) per se than whether those properties can be put to use in rhetorical struggles. Latour explains:

In other words, it is not *perception* which is at stake in this problem of visualization and cognition. New inscriptions, and new ways of perceiving them, are the results of something deeper. If you wish to go out of *your* way and come back heavily equipped so as to force others to go out of *their* ways, the main problem to solve is that of *mobilization*. You have to go and to come back *with* the “things” if your moves are not to be wasted. But the “things” have to be able to withstand the return trip without withering away. Further requirements: the “things” you gathered and displaced have to be presentable all at once to those you want to convince and who did not go there. In sum, you have to invent objects which have the properties of being *mobile* but also *immutable*, *presentable*, *readable*, and *combinable* with one another.<sup>34</sup>

Motion picture technology had all of the qualities of this sort of immutable mobile, a good indicator of its success as a scientific instrument. The instrument itself was mobile, but more importantly, so were the films. “Immutability,” in Latour’s sense, refers to the permanency of both the inscription process and the object or condition represented. Simply, the inscription must be relatively permanent, as films were, while providing a translation without any seeming corruption of the thing represented. The photographic image’s necessary physical connection (via light and chemical processes) to the object represented served to guarantee that the object was relatively uncorrupted by the recording process. The films were meant to be projected, so they were of course presentable, but because they were also photographs, they could be presented in a wide variety of ways, as illustrations in journal articles or as lecture slides, for example. In this way, the films could also be combined with other technologies, such as print technology, but the apparatus itself could be combined with others as well, such as the microscope. The “readability” or legibility of the technology is the most contentious aspect of any innovation, because the interpretation of new forms of inscription always requires negotiation within a discipline. Experts and innovators haggle over the meaning of signs until standards of production and protocols of interpretation emerge.<sup>35</sup> Generally speaking, however, motion pictures, like photography before them, were considered very legible for scientific purposes.

- Eiland and Michael W. Jennings, trans. Edmund Jephcott, Howard Eiland, and others (Cambridge, Mass.: Belknap, 2002), 101–136, here 116.
17. Benjamin, “The Work of Art in the Age of Its Technological Reproducibility (Second Version),” 104.
  18. Representative interventions in the debate about the role of modernity in a history of film style include the collection *Cinema and the Invention of Modern Life*, ed. Leo Charney and Vanessa Schwartz (Berkeley: University of California Press, 1995); David Bordwell, *On the History of Film Style* (Cambridge, Mass.: Harvard University Press, 1997), 141–46; Noel Carroll, “Modernity and the Plasticity of Perception,” *Journal of Aesthetics and Art Criticism* 59, no. 1 (Winter 2001): 11–18; Ben Singer, *Melodrama and Modernity: Early Sensational Cinema and Its Contexts* (New York: Columbia University Press, 2001); Charlie Keil, “‘To Here from Modernity’: Style, Historiography, and Transitional Cinema,” in *American Cinema’s Transitional Era: Audiences, Institutions, Practices*, ed. Charlie Keil and Shelley Stamp (Berkeley: University of California Press, 2004), 51–65; Tom Gunning, “Modernity and Cinema: A Culture of Shocks and Flows,” in *Cinema and Modernity*, ed. Murray Pomerance (New Brunswick, N.J.: Rutgers University Press, 2006), 297–315; and Frank Kessler, “Viewing Change, Changing Views: The ‘History of Vision’ Debate,” in *Film 1900: Technology, Perception, Culture*, ed. Annemone Ligensa and Klaus Kreimeier (New Barnet, U.K.: Libbey, 2009), 23–35.
  19. Among many other surveys discussed in chap. 4, see esp. Sabine Hake, *The Cinema’s Third Machine: Writing on Film in Germany, 1907–1933* (Lincoln: University of Nebraska Press, 1993).
  20. André Gaudreault, *Film and Attraction: From Kinematography to Cinema*, trans. Timothy Barnard (Urbana: University of Illinois Press, 2011).
  21. See, e.g., Kevin Repp, *Reformers, Critics, and the Paths of German Modernity: Anti-Politics and the Search for Alternatives, 1890–1914* (Cambridge, Mass.: Harvard University Press, 2000); Andrew Lees, *Cities, Sin, and Social Reform in Imperial Germany* (Ann Arbor: University of Michigan Press, 2002); and Dennis Sweeney, “Reconsidering the Modernity Paradigm: Reform Movements, the Social and the State in Wilhelmine Germany,” *Social History* 31, no. 4 (November 2006): 405–434.
  22. Ben Singer names this ambivalence “ambimodernity” and brings it to the attention of the film studies community in “The Ambimodernity of Early Cinema: Problems and Paradoxes in the Film-and-Modernity Discourse,” in Ligensa and Kreimeier, *Film 1900*, 37–51.

## 1. SCIENCE’S CINEMATIC METHOD

1. Charles Cros, “Inscription,” in *Oeuvres complètes*, ed. Louis Forestier and Pascal Pia (Paris: Pauvert, 1964), 135–136.
2. On the graphic method, see Merriley Borell, “Extending the Senses: The Graphic Method,” *Medical Heritage* 2, no. 2 (March/April 1986): 114–121; Robert G. Frank Jr., “The Telltale Heart: Physiological Instruments, Graphic Methods,

- and Clinical Hopes, 1854–1914,” in *The Investigative Enterprise: Experimental Physiology in Nineteenth-Century Medicine*, ed. William Coleman and Frederick L. Holmes (Berkeley: University of California Press, 1988), 211–290; Soraya de Chadarevian, “Graphical Method and Discipline: Self-Recording in Nineteenth-Century Physiology,” *Studies in History and Philosophy of Science* 24, no. 2 (June 1993): 267–291; and Robert M. Brain, “Representation on the Line: Graphic Recording Instruments and Scientific Modernism,” in *From Energy to Information: Representation in Science and Technology, Art, and Literature*, ed. Bruce Clarke and Linda Dalrymple Henderson (Stanford, Calif.: Stanford University Press, 2002), 155–177.
3. Wilhelm Braune and Otto Fischer, *The Human Gait*, trans. Paul Maquet and Ronald Furlong (Berlin and New York: Springer, 1987). In addition to *The Human Gait*, Braune and Fischer’s human motion studies included *Das Gesetz der Bewegungen an der Basis der mittleren Finger und im Handgelenk des Menschen* (Leipzig, 1887); *Über den Schwerpunkt des menschlichen Körpers mit Rücksicht auf die Ausrüstung des deutschen Infanteristen* (Leipzig, 1889), translated as *On the Centre of Gravity of the Human Body as Related to the Equipment of the German Infantry Soldier* by Paul Maquet and Ronald Furlong (Berlin and New York: Springer, 1985); *Bestimmung der Trägheitsmomente des menschlichen Koerpers und seiner Glieder* (Leipzig, 1892), translated as *Determination of the Moments of Inertia of the Human Body and Its Limbs* by Paul Maquet and Ronald Furlong (Berlin and New York: Springer, 1988); and Fischer’s *Theoretische Grundlagen für eine Mechanik der lebenden Körper* (Leipzig, 1906).
  4. Max Seddig, “Ueber Abhängigkeit der Brown’schen Molekularbewegung von der Temperatur,” *Sitzungsberichte der Gesellschaft zur Beförderung der gesammten Naturwissenschaften zu Marburg* 18 (1907): 182–188; Seddig, “Über die Messung der Temperaturabhängigkeit der Brownschen Molekularbewegung,” *Physikalische Zeitschrift* 9, no. 14 (15 July 1908): 465–468; Seddig, “Messung der Temperatur-Abhängigkeit der Brown’schen Molekularbewegung,” Habilitationsschrift, Akademie in Frankfurt a. M., 1909; Seddig, “Exacte Messung des Zeitintervalles bei kinematographischen Aufnahmen,” *Jahrbuch für Photographie und Reproduktionstechnik* 26 (1912): 654–657; and Seddig, “Messung der Temperatur-Abhängigkeit der Brown-Zsigmondyschen Bewegung,” *Zeitschrift für Anorganische Chemie* 73–74 (1912): 360–384.
  5. Hermann Braus, “Mikro-Kino-Projektionen von in vitro gezüchteten Organanlagen,” *Verhandlungen der Gesellschaft deutscher Naturforscher und Ärzte* 83, part 2 (1911): 472–475.
  6. For a fascinating account of cinema’s relationship to time and science, see Mary Ann Doane, *The Emergence of Cinematic Time: Modernity, Contingency, the Archive* (Cambridge, Mass.: Harvard University Press, 2002).
  7. Examinations of the relationship between illustrative materials and the agendas of scientists are increasingly popular in the history of science; a good, representative example is Martin Kemp, “Temples of the Body and Temples of the Cosmos: Vision and Visualization in the Vesalian and Copernican Revolutions,” in *Picturing*

- Knowledge: Historical and Philosophical Problems Concerning the Use of Art in Science*, ed. Brian S. Baigrie (Toronto and Buffalo, N.Y.: University of Toronto Press, 1996), 40–84. Two especially influential collections are Michael Lynch and Steve Woolgar, eds., *Representation in Scientific Practice* (Cambridge, Mass.: MIT Press, 1990); and Caroline A. Jones and Peter Galison, eds., *Picturing Science, Producing Art* (New York: Routledge, 1998). Cateljine Coopmans, Janet Vertesi, Michael E. Lynch, and Steve Woolgar, eds., *Representation in Scientific Practice Revisited* (Cambridge, Mass.: MIT Press, 2014) is an excellent recent collection.
8. For more on the relationship between motion pictures and scientific experiment, see the section on “The Multiple Functions of the Medical Film” in chap. 2 in this volume.
  9. On experimental systems and “dislocation” or “differential reproduction,” see Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford, Calif.: Stanford University Press, 1997), esp. chap. 5. Generally speaking, experimental systems are designed to produce incremental differences, which ultimately produce new inquiries and systems. But the balance between old and new is not symmetrical; my theory of disciplinary appropriation accommodates both the *correspondence* between disciplinary ideals and film and the *difference* between them, but the history I tell in this book favors the former. For more on the latter, see the conclusion in this volume.
  10. Gaston Bachelard, *The New Scientific Spirit*, trans. Arthur Goldhammer (Boston: Beacon, 1984), 13. See also Davis Baird, *Thing Knowledge: A Philosophy of Scientific Instruments* (Berkeley: University of California Press, 2004).
  11. Rheinberger, *Toward a History of Epistemic Things*, 21.
  12. Ian Hacking, *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science* (Cambridge: Cambridge University Press, 1983).
  13. For surveys of scientific uses of photography and film, see Karl Wilhelm Wolf-Czapek, ed., *Angewandte Photographie in Wissenschaft und Technik* (Berlin: Union Deutsche Verlagsgesellschaft, 1911); Martin Weiser, *Medizinische Kinematographie* (Dresden and Leipzig: Steinkopff, 1919); F. Paul Liesegang, *Wissenschaftliche Kinematographie* (Düsseldorf: Liesegang, 1920); Anthony R. Michaelis, *Research Films in Biology, Anthropology, Psychology, and Medicine* (New York: Academic, 1955); Virgilio Tosi, *Cinema Before Cinema: The Origins of Scientific Cinematography*, trans. Sergio Angelini (London: British Universities Film & Video Council, 2005); Timothy Boon, *Films of Fact: A History of Science in Documentary Films and Television* (New York: Wallflower, 2008); and Kelly Wilder, *Photography and Science* (London: Reaktion, 2009).
  14. The literature on this transition between chronophotography and film is vast, but one place to start is Deac Rossell, *Living Pictures: The Origins of the Movies* (Albany: State University of New York Press, 1998). On Janssen, see esp. the work of Jimena Canales, who describes the history of Janssen’s photographic revolver in the context of emerging cinematographic forms of representation in the following: “Photogenic Venus: The ‘Cinematographic Turn’ in Science and Its Alternatives,” *Isis* 93 (2002): 585–613; “Sensational Differences: The Case of the Transit of Venus,” *Cahiers François Viète* 1, nos. 11/12 (September 2007): 15–40; *A Tenth of*

- a Second: A History* (Chicago: University of Chicago Press, 2009), 87–115; and “Desired Machines: Cinema and the World in Its Own Image,” *Science in Context* 24, no. 3 (September 2011): 329–359.
15. Jennifer Tucker, *Nature Exposed: Photography as Eyewitness in Victorian Science* (Baltimore, Md.: Johns Hopkins University Press, 2005); or Tucker, “Photography as Witness, Detective, and Imposter: Visual Representation in Victorian Science,” in *Victorian Science in Context*, ed. Bernard Lightman (Chicago: University of Chicago Press, 1997), 378–408; see also Joel Snyder, “*Res Ipsa Loquitur*,” in *Things That Talk: Object Lessons from Art and Science*, ed. Lorraine Daston (New York: Zone, 2004), 195–221; as well as Wilder, *Photography and Science*.
  16. An excellent discussion of one scientist’s dissatisfaction with photography can be found in Sarah de Rijcke, “Drawing Into Abstraction. Practices of Observation and Visualisation in the Work of Santiago Ramón y Cajal.” *Interdisciplinary Science Reviews* 33, no. 4 (2008): 287–311. Ramón y Cajal found that photography could not capture the three-dimensionality of nerve cells as well as drawings.
  17. Thomas Schlich, “‘Wichtiger als der Gegenstand selbst’: Die Bedeutung des fotografischen Bildes in der Begründung der bakteriologischen Krankheitsauffassung durch Robert Koch,” in *Neue Wege in der Seuchengeschichte*, ed. Martin Dinges and Thomas Schlich (Stuttgart: Steiner, 1995), 143–174. See also Olaf Breidbach, “Representation of the Microcosm: The Claim for Objectivity in 19th Century Scientific Microphotography,” *Journal of the History of Biology* 35 (2002): 221–250.
  18. On the similarities between the graphic method and cinema, see Lisa Cartwright, “‘Experiments of Destruction’: Cinematic Inscriptions of Physiology,” *Representations* 40 (Fall 1992): 129–152; and Cartwright, *Screening the Body: Tracing Medicine’s Visual Culture* (Minneapolis: University of Minnesota Press, 1995).
  19. On Germany’s research infrastructure, see, e.g., Margit Szöllösi-Janze, “Science and Social Space: Transformations in the Institutions of *Wissenschaft* from the Wilhelmine Empire to the Weimar Republic,” *Minerva* 43 (2005): 339–360.
  20. Carl Cranz, “Über einen ballistischen Kinematographen,” *Deutscher Mechaniker-Zeitung* 18 (15 September 1909): 173–177. See also P. W. W. Fuller, “Carl Cranz, His Contemporaries, and High-Speed Photography,” *Proceedings of SPIE*, no. 5580, 26th International Congress on High-Speed Photography and Photonics (25 March 2005): 250–260; and Wilhelm Pfeffer, “Die Anwendung des Projektionsapparates zur Demonstration von Lebensvorgängen,” *Jahrbücher wissenschaftliche Botanik* 35 (1900): 711–745. On Pfeffer, see esp. Oliver Gaycken, “‘The Swarming of Life’: Moving Images, Education, and Views Through the Microscope,” *Science in Context* 24, no. 3 (September 2011): 361–380; and Gaycken, “The Secret Life of Plants: Visualizing Vegetative Movement, 1880–1903,” *Early Popular Visual Culture* 10, no. 1 (2012): 51–69.
  21. The best overview of Comandon’s life and work is Béatrice de Pastre and Thierry Lefebvre, eds., *Filmer la science, comprendre la vie: Le cinéma de Jean Comandon* (Paris: Centre national de la cinématographie, 2012).

22. On Messter, see Christian Ilgner and Dietmar Linke, "Filmtechnik: Vom Malteserkreuz zum Panzerkino," in *Oskar Messter: Filmpionier der Kaiserzeit*, ed. Martin Loiperdinger (Basel and Frankfurt: Stroemfeld/Roter Stern, 1994), 93–134, esp. 128–134; as well as Frank Kessler, Sabine Lenk, and Martin Loiperdinger, eds., *Oskar Messter—Erfinder und Geschäftsmann*, KINtop Schriften 3 (Basel and Frankfurt: Stoemfeld/Roter Stern, 1994). On Ernemann, see, e.g., the nod to the manufacturer in Hans Hennes, "Die Kinematographie der Bewegungsstörungen," *Die Umschau* 15, no. 29 (1911): 605–606; as well as Hanns Günther, "Mikrokinematographische Aufnahmeapparate," *Film und Lichtbild* 1, no. 1 (1912): 4–6; 1, no. 2 (1912): 13–14.
23. On popular scientific cinema, see Thierry Lefebvre, "The Scientia Production (1911–1914): Scientific Popularization Through Pictures," *Griffithiana* no. 47 (May 1993): 137–153; Oliver Gaycken, "'A Drama Unites Them in a Fight to the Death': Some Remarks on the Flourishing of a Cinema of Scientific Vernacularization in France, 1909–1914," *Historical Journal of Film, Radio and Television* 22, no. 3 (2002): 353–374; and Gaycken, *Devices of Curiosity: Early Cinema and Popular Science* (Oxford and New York: Oxford University Press, 2015). For an excellent account of popular science films in the United Kingdom, see Boon, *Films of Fact*. On the entwinement of scientific experiment, projection, popular science, and Victorian physics, see Simon Schaffer, "Transport Phenomena: Space and Visibility in Victorian Physics," *Early Popular Visual Culture* 10, no. 1 (February 2012): 71–91. On popularization in science in general, see Roger Cooter and Stephen Pumfrey, "Separate Spheres and Public Places: Reflections on the History of Science Popularization and Science in Popular Culture," *History of Science* 32, no. 97 (1994): 237–267.
24. Readers were asked to write the editor for details; see "Verzeichnis wissenschaftlich und technisch wertvoller Films," *Film und Lichtbild* 1, no. 2 (1912): 16; or "An unsere Abonnenten!" *Film und Lichtbild* 2, no. 5 (1913): 84.
25. For reports of screenings, see "Wissenschaft und Lichtspiele," *Bild und Film* 1, no. 2 (1912): 49–50; "Kino und Wissenschaft," *Bild und Film* 1, no. 2 (1912): 55; W. Thielemann, "Kinematographie und biologische Forschung," *Bild und Film* 3, no. 7 (1913/1914): 171–172; and "Wissenschaftliche Abende," *Film und Lichtbild* 1, no. 3 (1912): 30–31.
26. "Ein neues wissenschaftliches Kino," *Film und Lichtbild* 1, no. 5 (1912): 62. It is possible that the Fata Morgana was the only one of its kind.
27. See Thierry Lefebvre, *La chair et le celluloid: Le cinéma chirurgical du Docteur Doyen* (Brionne: Jean Doyen éditeur, 2004), for a discussion of the controversy surrounding the theft and possible unauthorized exhibition of Parisian doctor Eugène-Louis Doyen's surgical films in the early 1900s. See also chap. 2 in this volume.
28. For example, Wilhelm Richter, a Berlin teacher and school reformer, often wrote on scientific cinema in the popular press, cheering all efforts to bring new views to public perception. See "Der Kinematograph als naturwissenschaftliches Anschauungsmittel," *Naturwissenschaftliche Wochenschrift* 12, no. 52 (28 December 1913): 817–820.

29. On the use of film in university teaching, see Franz Bergmann, "Der Kinematograph im Hochschulunterricht," *Bild und Film* 2, no. 2 (1912/1913): 48; Wilhelm Richter, "Hochschulkinematographie," *Bild und Film* 2, nos. 11/12 (1912/1913): 253–257; and L. Segmiller, "Das Skizzieren nach Lichtbildern bei Tageslicht und künstlicher Beleuchtung," *Film und Lichtbild* 1, no. 4 (1912): 35–39.
30. One survey of the contemporary use of microcinematography notes, "Films of the latter [Ernst Sommerfeldt] are available commercially from Ernemann and depict crystallographic phenomenon," so apparently whether a research film made it into theaters depended on both the researcher's willingness and the manufacturer's evaluation of its popular appeal. On this example, see Ernst Sommerfeldt, "Über flüssige und scheinbar lebende Kristalle; mit kinematographischen Projektionen," *Verhandlungen der Gesellschaft deutscher Naturforscher und Ärzte* 79, part 2 (1907): 202. The survey of microcinematography is Engelhard Wychgram, "Aus optischen und mechanischen Werkstätten IV," *Zeitschrift für wissenschaftliche Mikroskopie und für mikroskopische Technik* 28 (1911): 337–361, esp. 351–361.
31. On "mechanical objectivity," see Lorraine Daston and Peter Galison, "The Image of Objectivity," *Representations* 40 (Fall 1992): 81–128; and Daston and Galison, *Objectivity* (New York: Zone, 2007).
32. On the difference between instruments for experimentation and for demonstration, see Thomas L. Hankins and Robert J. Silverman, "The Magic Lantern and the Art of Demonstration," in *Instruments and the Imagination* (Princeton, N.J.: Princeton University Press, 1995), 37–71.
33. Bruno Latour, "Visualization and Cognition: Thinking with Eyes and Hands," *Knowledge and Society: Studies in the Sociology of Culture Past and Present* 6 (1986): 1–40, here 5. Brian Winston has also considered Latour's work in relation to film: "The Documentary Film as Scientific Inscription," in *Theorizing Documentary*, ed. Michael Renov (London and New York: Routledge, 1993), 37–57.
34. Latour, "Visualization and Cognition," 7 (emphasis in original).
35. See esp. Nicolas Rasmussen, *Picture Control: The Electron Microscope and the Transformation of Biology in America, 1940–1960* (Stanford, Calif.: Stanford University Press, 1997); Bernike Pasveer, "Knowledge of Shadows: The Introduction of X-Ray Images in Medicine," *Sociology of Health and Illness* 11, no. 4 (December 1989): 361–381; and Edward Yoxen, "Seeing with Sound: A Study of the Development of Medical Images," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, ed. Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch (Cambridge, Mass.: MIT Press, 1987), 281–303.
36. Anne Harrington, *Reenchanted Science: Holism in German Culture from Wilhelm II to Hitler* (Princeton, N.J.: Princeton University Press, 1996). For an account of earlier debates about mechanistic approaches in science, see Peter Hanns Reill, *Vitalizing Nature in the Enlightenment* (Berkeley: University of California Press, 2005).
37. Henri Bergson, *Creative Evolution*, trans. Arthur Mitchell (New York: Random House, 1944). Hereafter cited parenthetically. Bergson indicates in the opening footnote of chap. 4 that he began thinking about science and film during his 1902–1903 course on the "History of the Idea of Time" at the Collège de France.