RACAR : Revue d'art canadienne
Canadian Art Review

Pedagogical Interventions: The Physics Photographs of Berenice Abbott

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Volume 41, Number 2, 2016

The Nature of Naturalism : A Trans-Historical Examination
La nature du naturalisme : un examen transhistorique

URI: https://id.erudit.org/iderudit/1038073ar
DOI: https://doi.org/10.7202/1038073ar

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Publisher(s)

UAAC-AAUC (University Art Association of Canada | Association d'art des universités du Canada)

ISSN

0315-9906 (print)
1918-4778 (digital)

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Cite this article

O'Reilly, C. (2016). Pedagogical Interventions: The Physics Photographs of Berenice Abbott. *RACAR : Revue d'art canadienne / Canadian Art Review*, *41*(2), 77–90. https://doi.org/10.7202/1038073ar

Article abstract

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Pedagogical Interventions: The Physics Photographs of Berenice Abbott

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À la fin des années 1950, la photographe états-unienne Berenice Abbott collabore avec le Physical Science Study Committee du Massachusetts Institute of Technology créant des photographies pour un manuel de physique d'enseignement secondaire. Les images y sont mises en relation avec des graphiques et des textes afin de démontrer le fonctionnement de phénomènes tels que la gravité, le magnétisme et le mouvement des vagues. Ce genre photographique est souvent décrit comme ayant un lien direct à la nature et comme le produit d'un medium intrinsèquement «naturaliste» dispensé d'une quelconque médiation. Cependant, dans l'œuvre de Abbott, c'est l'intervention visible de la technologie photographique et l'identification des conventions de la représentation qui permettent aux images de transmettre le savoir. Cet article analyse les stratégies utilisées par Abbott afin de remettre en question les suppositions quant au concept de naturalisme dans l'usage de la photographie dans un contexte éducatif.

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The US photographer Berenice Abbott is best known for her portrait photographs taken in the 1920s and for her 1930s documentary series *Changing New York*. Scholars have paid somewhat less attention to her subsequent turn to science as a photographic subject, an endeavour that defined the latter half of her career.[1] Abbott's scientific photographs appeared in magazines, books, and exhibitions from 1939 onward, and ranged in subject matter from biology and physics to industry and technology. Of particular interest here is her little-studied work for the Physical Science Study Committee (PSSC) at the Massachusetts Institute of Technology (MIT) in the late 1950s. Physicists and educators formed the PSSC in 1956 to reform high school physics curricula, and received funding from the National Science Foundation.[2] In the post-war and Cold War period, politicians and the US public tended to view science education as a matter of national security, and federal support for curriculum reform was strong.[3]

While working for the PSSC, Abbott developed a specific approach to using photography to explain physics. In one of her best-known examples—a multiple-flash exposure of a bouncing ball—the image of a ball repeats itself in four diminishing arcs against a flat, black background. | fig. 1 | The potential for this image to convey its content—a law of motion—relies on the viewer's understanding of how photographic technology works. Drawing on conventions of photography already established and visually familiar, Abbott makes strategic use of traces in the prints that viewers will recognize as manifestations of the photographic process. These lead the viewer to see the images of the ball as points in a diagram, with the help of information provided by accompanying text, equations, and drawings. Another widely circulated photograph depicts the motion of a spinning wrench, | fig. 10 | while others portray magnetism, rays of light, or wave motion. | fig. 5 | In this article, I will explore the development and reception of Abbott's scientific photography practice, then analyze exactly how some of these images were useful in educating students about the natural world. Working against typical assumptions about the role of photographic naturalism in scientific photographs, I will argue that the intelligibility of Abbott's images is based on their relation to established methods of representation rather than on a natural link between the image and the phenomena in question. Furthermore, these images explicate principles using certain traces of the photographic process that are visible in the print and recognizable to viewers.

1. Monographs on Abbott include Hank O'Neal, *Berenice Abbott: American Photographer* (New York, 1982), Julia Van Haaften, *Berenice Abbott, Photographer: A Modern Vision* (New York, 1989). Scholars of Abbott who focus on her portraiture and *Changing New York* include Peter Barr, Sarah Miller, and Bonnie Yochelson. Treatments of the science work are found in Hank O'Neal's

introduction, and Terri Weissman's *The Realisms of Berenice Abbott* (Berkley, 2011), chapter five. Abbott's scientific work and related archival material was the focus of a 2012 exhibition at the MIT Museum entitled "Berenice Abbott: Photography and Science: An Essential Unity" curated by Gary van Zante, and the book *Documenting Science*, edited by Ron Kurtz, with essays by Julia Van Haaften and John Durant, (Göttingen, 2012). Some images were also included in the 2015 exhibition *Revelations: Experiments in Photography* at London's Science Museum. See Ben Burbridge, ed., *Revelations: Experiments in Photography* (London, 2015).

2. For a history of the PSSC, see James R. Killian, *The Education of a College President: A Memoir* (Cambridge, MA, 1985), 166–73, Oscar L. Brauer, "Conventional Physics against PSSC Physics," *Science Education* 49, 2 (March 1965), 170–71, and George F. Smith, "PSSC Applied Physics," *The Physics Teacher* 3, 7 (1965): 312–17.

3. See for example John L. Rudolph, *Scientists in the Classroom: The Cold War Reconstruction of American Science Education* (New York, 2002). Rudolph notes that while federal funding for projects to improve science education in this period was tied to the Cold War, the scientists themselves had many and varied goals that were not tied to nationalism or political ideology.

4. Literature that has explored this includes Soraya De Chadarevian and Nick Hopwood, eds., *Models: The Third Dimension of Science* (Stanford, CA, 2004); Klaus Hentschel, *Mapping the Spectrum, Techniques of Visual Representation in Research and Teaching* (Oxford, 2002); and Martin Rudwick, "The Emergence of Visual Language for Geological Science, 1760–1840," *History of Science* 14 (1976): 149–95.

5. "naturalism, n." *OED* Online. Oxford University Press, September 2016. Web.

6. Lorraine Daston and Peter Galison explain how scientific photography was in some cases valued on this basis in "The Image of Objectivity," *Representations* 40, Special Issue: Seeing Science (Autumn, 1992): 81–128.

7. For example, the reactions to Eadweard Muybridge's work or to x-ray photography in the nineteenth century, or the work of Harold Edgerton, *Flash! Seeing the Unseen by Ultra High-Speed Photography* (Boston, 1939) in the early twentieth.

8. William J. Mitchell argued this extensively in *The Reconfigured Eye: Visual Truth in the Post-Photographic Era* (Cambridge, MA, 1992), and the

My argument that the utility of the photographs relies on the presence of key visual conventions and other modes of representation goes against standard ideas about the way we interpret scientific photography. While scientific photographs are often considered as having access to a pre-existing, untouched, natural world, the efficacy of Abbott's images actually depends on a set of constructed physical conditions and, more notably, on these conditions being apparent to the viewer. The visibility—not the suppression—of image-making techniques facilitates knowledge. In spite of this, scientific representations are often either reduced to the subjects they represent or considered transparent windows through which we see autonomous data.[4] In photography, this transparency is often framed as possible because of a naturalistic representational style that is assumed to be inherent in the medium. The *Oxford English Dictionary* defines naturalism as "a style or method characterized by close adherence to, and representation of, nature or reality," and as "adherence or attachment to what is natural; indifference to convention."[5] Photographs have been described as having this special unmediated, mechanical, or "indexical" relationship to the real, and it is this characteristic that has allowed photography to claim a position both as a modern art form and as a reliable scientific tool. In some cases, indexicality and an emphasis on the mechanical are used to argue that photography depicts things in a way true to human sight.[6] In others, photography is often considered a modern art or modern science because of the ways in which it goes beyond human vision in order to gain new access to natural realms.[7] Both formulations assume that photography has built-in access to the world, and these views persist today, as indicated by the number of historians who adopt the stance that the crucial shift brought on by digital photography is that it somehow undermines this natural relationship.[8]

In the history of photography, this concept of naturalism has been flexible and nebulous, which has allowed for a certain level of imprecision in the description of photography's scientific or pedagogical value. To designate a photograph as naturalistic or as having a direct connection to nature in fact tells us very little about how it operates, how it looks, or why it is useful for science.[9] To hinge what photography accomplishes on its supposedly inherent naturalism obscures its more interesting and crucial components: the intentional invention of different photographic technologies to serve a particular purpose, and the various material and intellectual interventions that make invisible natural phenomena visible in photographs. To think of Abbott's images as simply unmediated would actually conceal the ways in which they portray physical phenomena. Scholars have noted many examples in the history of scientific photography in which knowledge is produced, not revealed, by the camera. In sum, while photography is often described as having an inherent connection to the natural world that can validate it as an art form or as a scientific tool, this notion does not account for its effects or uses.[10]

Abbott ran up against these problems when discussing her work. She tended to use the term realism rather than naturalism in relation to her practice, but problematized the concept of realism in the precise way in which I intend to problematize the notion of naturalism here. The two words have different connotations and different histories, but both are used to mobilize a number of assumptions about photography that continue to cause us to gloss over the more instructive complexities of scientific representation. As Terri Weissman noted in *The Realisms of Berenice Abbott: Documentary Photography and Political Action*, Abbott used the word realism in a manner very specific to her own goals, that is, as not always tied to the notion that the camera has direct, unmediated access to the world.[11] Abbott felt strongly that we do not need to imagine photography as a purely mechanical process in order to trust it as an informative and communicative medium. Moreover, she was very sceptical of attempts to separate the art from the science in her images and argued that photography was a perfect blend of human ideas and technology. Drawing on prevalent terminology and traditions in photography, she attempted to resolve the ways in which they conflicted. For Abbott, photography, on the one hand, "sees" with absolute fidelity, and, on the other, is separate from and goes beyond human vision and its abilities. In a 1938 article on lenses, she wrote,

> Photography, we have said, is a new vision of life, a profoundly realistic and objective view of the external world. In the all-seeing and minute observation of the camera eye, we see what we never saw before, a wealth of minutiae, the broad sweep of panorama and cloud. What the human eye observes casually and incuriously, the eye of the camera, the lens, notes down with relentless and inescapable fidelity…. This unique and powerful quality of the photograph has indeed established a new esthetic of art, an esthetic based on stern realism as the new vision of life. But the new esthetic could not function were it not for the tools and instruments with which present-day science has supplied photography.[12]

With regard to scientific photography specifically, Abbott, in her 1941 *Guide to Better Photography*, argued that "when the first stroboscopic photographs were exhibited, it was evident that in them was to be seen a *real* hyperreality, a true fantasy beyond what the subconscious could concoct… here at last photography sees with its own eye, untouched by any memories of how painters saw in the past."[13] A decade later, in an address to the Aspen Institute that criticized pictorialism, Abbott argued for photography to "walk alone" and "be itself" on the grounds of both its fidelity to vision and its autonomy from it.[14] While Abbott believed that in scientific work, a new photographic aesthetic emerges that is so physically rooted in nature as to be beyond other kinds of pictures, her photographs relate to nature via visual references to elements that had been used in earlier photographs and scientific representations. Abbott would not have denied the importance of these references in her scientific work, since for her this photographic aesthetic, while connected to the real in a unique way, is also composed through an investment of "human intelligence."[15] Although she is known as an advocate for photographic realism, she is in fact quite clear on the influence that pictorial traditions from other media have had on the history of photography, and is also very specific about the fact that the camera lens does not see like a human eye, and that the photographer must learn to see like a camera.[16]

Weissman argues that Abbott's interest in photography was based on its ability to maximize the communicative potential between the photographer and an engaged, empowered viewer who would complete the work of the image, and that this approach characterizes not just her scientific work but her entire career.[17] Rather than separating the photograph's scientific authority from its status as a constructed object, this framework of communication

assumption that digital and analog photography have fundamentally different relationships with the real permeates much scholarship on photography. For a critique of it, see W.J.T. Mitchell's article "Realism and the Digital Image," which has been republished in *Image Science: Iconology, Visual Culture, and Media Aesthetics* (Chicago, 2015).

9. See the Daston and Galison article cited above for examples of this, as well as Jennifer Tucker's *Nature Exposed: Photography as Eyewitness in Victorian Science* (Baltimore, 2005).

10. Other writings that inform this foundational point are Josh Ellenbogen on Étienne-Jules Marey in "Camera and Mind," *Representations* 101 (Winter 2008): 86–115 (Abbott in fact pursued some of the same visual motifs created by Marey); Joel Snyder and Neil Walsh Allen, "Photography, Vision, and Representation," *Critical Inquiry* 2, 1 (Autumn 1975): 143–69; and Robin E. Kelsey, "Viewing the Archive: Timothy O'Sullivan's Photographs for the Wheeler Survey, 1871–74," *The Art Bulletin* 85, 4 (Dec. 2003): 702–23.

11. Weissman, *Realisms*, 2.

12. "Photography by Berenice Abbott, Lenses: Optics of the Camera Eye, Project: Training the Human Eye to See as the Lens Does," Copyright, 1938, Art Adventure League, Inc. Berenice Abbott Collection, MIT Museum Archive, (hereafter Abbott MIT Archive) Box 15. The content of this article is also published as a chapter on lenses in Berenice Abbott's *A Guide to Better Photography* (New York, 1941).

13. Abbott, *Guide to Better Photography*, 173–74. Emphasis in original.

14. Berenice Abbott, "It Has to Walk Alone," address given at the Aspen Institute in 1951 and published in *American Society of Magazine Photographers NEWS*, November 1951. Abbott MIT Archive, Box 2.

15. See Abbott, *Guide to Better Photography*. Also, in "What the Camera and I See," *ARTNews*, September 1951, 36–37, Abbott wrote, "I see the photograph as a statement of affirmation, built of wonder and curiosity. By the choice of subject and the special treatment given a subject, it is as personal as writing or music; while by the fact that it works with an instrument to record a segment of reality given and already made; unchangeable so to speak, it is impersonal, to the highest degree: this is for me its interest: the union of the personal and impersonal."

16. Abbott writes that there is a great risk if photographers "accept

highlights both Abbott's interpretive authorship and the photographs' factual content. It thus leaves open the possibility of analyzing more precisely how the scientific photographs operate as visual pedagogy. Weissman's work also paves the way for understanding that it is through their relation to other examples of photography, drawing, and diagramming that Abbott's images are pedagogically useful. They present themselves as carefully constructed photographic interventions, not as transparent windows, and incorporate visible traces of the photographic process and accompanying text or numbers that lead the viewer to understand the photograph in reference to other familiar representations.

In order to address Abbott's representational strategies, we must also map the trajectory of her scientific photography practice.[18] Abbott moved toward scientific subjects in the late 1930s, as her *Changing New York* project wound down. In April 1939, a letter she wrote to her friend Dr. Charles C. Adams, zoologist and director of the Albany-based New York State Museum, contained what she called a "treatise," which laid out a role for the photographer as "a friendly interpreter between science and the layman."[19] Abbott began to experiment on her own and took commercial assignments; a spread on agricultural research that included her photographs was published in *Life* magazine in June 1939. This led to an invitation to publish her photograph of nasturtiums grown using hydroponics in a science text from Ginn and Co. Educational Publishers.[20] In her 1941 *Guide to Better Photography* Abbott expressed her view that science was the ideal subject for the future of the field of photography.[21] In the 1940s she also developed what she called her "supersight" technique, or projection photography. This way of obtaining an extremely high level of detail very close up involved projecting and enlarging an image before exposure. In a dark room, the object was lit from the front, and positioned behind the lens, thus projecting an image onto film in front of the camera that could then be exposed. By enlarging the object instead of the negative, Abbott achieved prints with a fuller range of tones and less grain, such as in her treatments of a tangle of grass roots, a fish, and an apple. She also experimented with using this technique for portraiture. Throughout this period, Abbott further sought to acquaint herself with publishers and scientists who shared her interest in images that could help the general public understand science. She continued to experiment through the development of specialized photographic techniques and equipment. She also started a business, the House of Photography, to patent her inventions.

From 1944 to 1945, Abbott worked as photography editor of *Science Illustrated*, where she selected and also created photographs for publication. Ideas jotted down in a notebook from this time include a series of supersight photographs of everyday objects, a series on "laws of nature," and another on the seasons. In these projects, she was already thinking about using photography to visualize the non-visual. For example, she asked herself, in regard to the feeling of cold, "can we photograph sensations?"[22] In 1947, plans for an exhibition in Paris included several supersight photographs, which Abbott exhibited the following year at the Museum of Modern Art in *In and Out of Focus*, a show curated by Edward Steichen.[23] The supersight photos also appeared in an exhibition at the Akron Institute of Art in 1950.[24] In 1948, Abbott contributed several

the lens as being identical with or equal to the eye. On this fallacy, many a fine picture is wrecked." Abbott, *Guide to Better Photography*, 56. She also describes the complex ways in which a photographer must engage with optics in order to create the image he or she desires. The lens is both conceived using the analogy of the eye, but understood as very different from our eye. Abbott, *Guide to Better Photography*, 160–62

17. Weissman, *Realisms*, see chapter five.

18. This section draws from the work of Weissman, O'Neal, and the MIT Museum exhibition *Berenice Abbott: Photography and Science: An Essential Unity* in addition to hitherto unaddressed archival material.

19. The letter is in the Berenice Abbott Papers, Manuscripts and Archives Division, The New York Public Library (hereafter Abbott NYPL), folder 6.28.

20. Abbott NYPL, folder 6.28. Letter from Ginn and Co., Nov. 20, 1939.

21. Abbott, *Guide to Better Photography*, 174.

22. Abbott NYPL, folder 10.3.

23. Abbott MIT Archive, box 15 for the Paris exhibition. Abbott NYPL, folder 5.65 for the MoMA exhibition.

24. Abbott NYPL, folder 1.8 for the Akron exhibition.

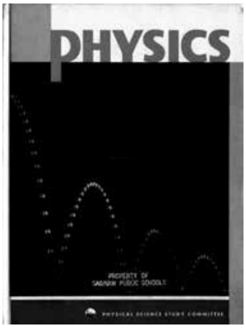


Figure 1. Physical Science Study Committee, *Physics* (D.C. Heath, 1960) with Abbott's "A Bouncing Ball in Diminishing Arcs" on front cover.

photographs, including a close up view of a magnolia plant, to the *American High School Biology* textbook, published by Harper and Brothers.[25] Abbott worked on ideas for a book on electricity in the early 1950s in a laboratory at Harvard, as well as for an unrealized book of supersight images in collaboration with Muriel Rukseyer and the publisher Doubleday. By 1953 her reputation in the field of science photography had led to an invitation to publish an image for the cover of *Scientific Monthly*.[26] Abbott's *New Guide to Better Photography*, a revised and updated version of her 1941 *Guide to Better Photography*, was published in 1953. It contained science photographs, including an experiment in photographing waves, a technique she would employ six years later at MIT.[27] In spite of many unrealized projects and an overall lack of strong support, Abbott remained committed to the subject of science and continued to experiment.

In 1956, Abbott learned of the activities of the Physical Science Study Committee (PSSC). Two years later, as a result of her connections with Doubleday, and with the encouragement of Robert Cooke, editor of *Genetics* magazine, and L. Bernard Cohen, her friend and a member of the PSSC, Abbott was hired by Dr. Elbert P. Little to help with a new physics textbook.[28] This was the opportunity Abbott had been waiting for; it allowed her to focus on her goals for scientific photography in a setting where she was supported financially and could collaborate with scientists. The project entailed teaching high school students the basic laws of physics. In the classroom, abstract concepts were instantiated for students through experiments. The PSSC wanted to see education in the sciences reflect the actual work of modern physicists.[29] The emphasis was on experimentation and on teaching students to understand the process of the discovery of fundamental laws rather than just having them memorize facts. Students were to find their own answers through genuine experimentation rather than perform pre-set experiments to verify answers they already knew.[30] While some teachers felt that the PSSC Physics course was too esoteric and did not focus enough on the real-world information that they believed students needed, others considered it a revelation. Its appeal and the strong federal financial support it received should be understood in the context of the push during the Cold War by educators and the government to link scientific progress with national pride and to inspire young people to pursue scientific endeavours.[31] During the project, Abbott collaborated with physicists and technicians to construct the scenarios that led to the photographs, and she experimented with materials and equipment as she went along. She later described her time with the PSSC as very productive: this in spite of the many challenges that she faced as a woman in a male-dominated environment and an artist amongst scientists who were not convinced her expertise was necessary.[32] In addition, she did not have control over exactly how the images appeared in the text. After the 1960 edition of PSSC *Physics* was published, Abbott was pushed out of the project, but her images were used in all seven editions, the last being published in 1991.

In addition to their use in the textbook, and in an exhibition called *Portraits from Physics* organized by Educational Services Incorporated (the distributor of PSSC materials), the images were also shown at the New School for Social Research in New York (where Abbott had taught for many years) and were published in several articles in the early 1960s. The publishers of the *Harper*

25. Charlotte L. Grant, H. Keith Cady, and Nathan A. Neal, *American High School Biology* (New York, 1948).
26. Abbott's collaborations with Cohen and Rukseyer were discussed in the MIT Museum exhibition *Berenice Abbott: Documenting Science*. The letter from Scientific Monthly is in Abbott MIT Archive, Correspondence M-Z.
27. Abbott, *New Guide to Better Photography*, illustration no. 9.
28. Abbott MIT Archive, Box 2, Folder 56, holds the letter from Richard Winslow at Doubleday mentioning the PSSC. Weissman cites the role of Cooke, *Realisms*, 190.
29. See E.P. Little, "PSSC: A Physics Program," *Educational Leadership* 17, 3 (December 1959): 167–69, 192.
30. *Physics*, preface by James R. Killian, V-VI. Killian writes, "physics is presented not as a mere body of facts, but basically as a continuing process by which men seek to understand the nature of the physical world."
31. For more on the federal government's particular interest in training future scientists at this time, see for example Daniel Lee Kleinman and Mark Solovey, "Hot Science/Cold War: The National Science Foundation after World War II," *Radical History Review* 63 (1995): 110–39.
32. See Julia van Haaften's essay in *Documenting Science* (Göttingen, 2012), 10 and Weissman, *Realisms*, 198.

Encyclopedia of Science also asked Abbott for her permission to include some of her photographs.[33] An exhibition of the PSSC images, titled *The Image of Physics*, organized by the Currier Museum of Art in Manchester, New Hampshire, and circulated by the Smithsonian Institution Traveling Exhibition Service, was presented in dozens of schools, libraries, and museums in the US between 1961 and 1965. The press release for this exhibition described it as an "educational exhibition of high aesthetic quality" and claimed that Abbott was "photographically recording experiments with scientific detachment and eliminating all features that might be due to accident" in order to create "an imposing visual presentation of the basic laws of physics as they might be demonstrated in a laboratory under ideal conditions." It also stated that "multi-flash and high speed photography, which Miss Abbott used extensively in the studies of motion, not only record the experiments but are essential to their success since physics must use the camera as a necessary tool in these investigations."[34] This press release betrays a struggle to reconcile the camera as "detached" witness with photography as an active process of crafting, selecting, and specifying.

Over the course of the 1960s, Abbott's scientific photographs found another home in three science books targeted at students as well as at a wider audience. *Motion*, *Magnet*, and *The Attractive Universe*, all published by World Publishing Company, were developed with Abbott's full involvement and feature text and images in equal prominence. Much of the mathematics, however, was left out, and the concepts were presented in a more general, less technical way that would be suitable for a general audience. At World Publishing Company, Abbott collaborated with E.G. Valens, known at the time as a journalist and non-fiction writer.

In later years, her science work was included in *Once Visible* at the MoMA in 1974 and was the focus of *The Beauty of Physics* at the New York Academy of Sciences in 1987. From the beginnings of her interest in scientific photography and throughout the subsequent decades, Abbott's work moved back and forth across the practices of art and scientific pedagogy, and was often discussed in relation to the boundaries of human vision and to the importance of using compelling images in science education.[35] In spite of the resistance with which she was often met, Abbott pursued an image-making practice she regarded as simultaneously educational and artistic.

I now turn to a close look at the images themselves. A stroboscopic photograph of balls in motion appears in the PSSC textbook in a section on vectors, which are quantities involving both magnitude and direction, usually depicted by a line segment. | fig. 2 | As the text explains, the vector itself is already a visualization: "The length of the [straight line segment] gives the magnitude, and its direction specifies the direction in space."[36] The caption explains that horizontal strings traverse the image six inches apart and that this information can be used along with measurements of the spatial displacements and the flash speed to calculate velocity and analyze the motion of the ball in terms of vectors. The photograph thus operates like a graph. Its *mise-en-page* alongside three drawn graphs is a further cue to use it in this way. | fig. 3 | Here, Abbott composed an image to correspond to the mathematical concept, using physical objects, the technology of photography, and

33. Abbott MIT Archive, Box 3, Folder 4, contains documents on ESI's *Portraits from Physics*. The images were also published in *US Camera* 23, 2 (Feb. 1960): 34–39, 112; "Camera Catches Laws of Nature," *Popular Science* (Feb. 1960): 92–94; "Laws that Can't Be Broken," *Nature and Science* 1, 13 (Apr. 3, 1964): 8–9; *Camera* 4 (Apr. 1964); *The New York Times Magazine*, 17 May 1959; and in James R. Newman, ed., *The Harper Encyclopedia of Science* (New York, 1963)

34. Abbott NYPL, folder 8.1 and Smithsonian Institution Archives, Record Unit 290, Smithsonian Institution, Traveling Exhibition Service, Records.

35. This introduction of her work from IBM's *Think* magazine is a good example: "By combining great imagination and several photographic techniques, such as time exposure and stroboscopic flash, Berenice Abbott has produced images so vivid that some of them show students more than they see in the lab." *Think* 28, 2 (February 1962): 2, 6.

36. *Physics*, Physical Science Study Committee (D.C. Heath, 1960), 83.

37. Weissman, *Realisms*, 191.

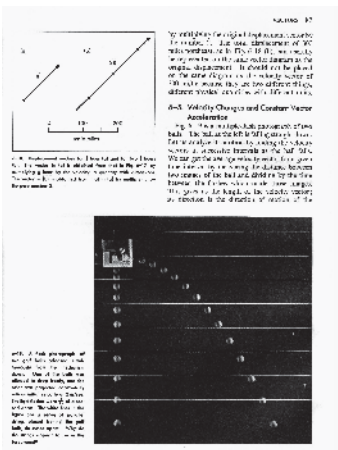
38. Nelson Goodman, *Languages of Art* (Indianapolis, 1976), 229–30.

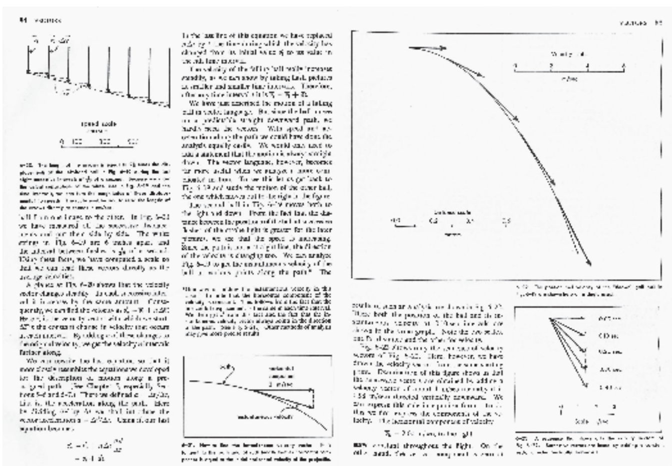
39. John Bender and Michael Marrinan, *The Culture of Diagram* (Stanford, 2010), chapters two and six.

the accompanying text and graphs. The students are then encouraged to make calculations directly on the photograph.

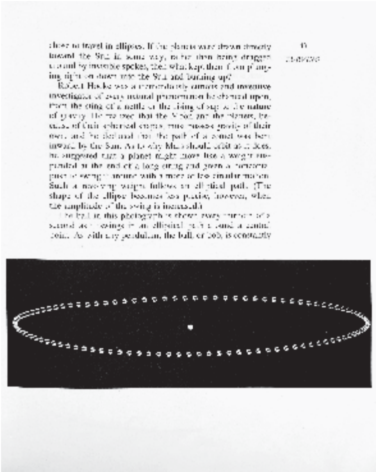
To create this image, a mechanism at top left released two balls simultaneously, one outward toward the right side of the frame and one straight downward, both in front of a black backdrop and a set of strings positioned horizontally at equal intervals. A strobe light was then used to create a multiple exposure photograph, which was cropped to eliminate the set-up. Far from simply capturing a phenomenon that exists in the world, the balls were manipulated to create a graph of their own motion through an elaborate process, customized to the technology and by the technology, in order to allow for the desired analysis. One needs to be following along in the vector lesson in order to understand the image in the way Abbott and the PSSC scientists intended.

A graph involving axes, points, and regular numeric intervals is one type in a broad category of images that can be characterized as diagrams. Weissman notes that Abbott's techniques made phenomena "draw their own diagrams" and thus address how real events relate to physics theory.[37] For the purposes of this study, I define a diagram as an image that consists of components situated in measurable relationships, and that is accompanied by a system of constraints that makes these relationships refer to real world correlates. For this definition I draw on the work of Nelson Goodman, who identifies a diagram as less "replete" than other images, in the sense that it relies on measurably distinct bits of information and has parts that can be ignored while retaining the diagram's intended meaning.[38] John Bender and Michael Marrinan develop these ideas further in their suggestions that diagrammatic representation and diagrammatic thinking should be defined as open-ended and participatory.[39] They argue that diagrams are tools with which to think, completely identifiable neither with nature nor with artifice, that provide the opportunity for experimentations that depart from the original conditions that engendered the representation. Diagrams correlate to external things in specifically defined ways, but they also have elements that are free-floating and can be recombined with aspects of the world in new ways, potentially





Figures 2, 3. Physical Science Study Committee, *Physics* (D.C. Heath, 1960), 83 (left) and 84–85 (right).



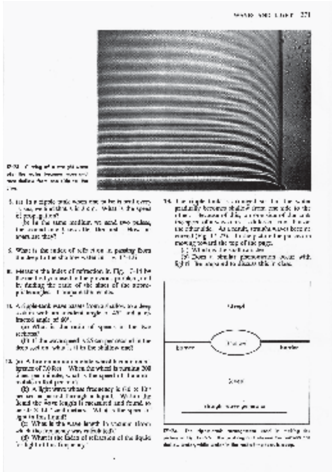


Figure 4 (left). E.G. Valens and Berenice Abbott, *The Attractive Universe* (Cleveland: World Publishing Company, 1969), 43.

Figure 5 (right). Physical Science Study Committee, *Physics* (D.C. Heath, 1960), 271.

shaping knowledge or generating new knowledge.[40] For Bender and Marrinan, a diagram is not the same as what it represents; it is a new autonomous thing.[41] Additionally, the components of the images that are correlated with objects in the world are presented in a blank space, as opposed to a space that correlates with ours. Abbott achieves this effect by photographing objects against a black background, by cropping so as to remove the image from the set-up and from a clear sense of real space, and by using a high contrast of light and dark. As Bender and Marrinan suggest, visual formalization or idealization unmoored from reality allows the discrete points the possibility of applying to other situations in a generalized way.[42] Because the visual components of the image must be understood to represent a law that describes a general phenomenon, not just a singular occurrence, the photograph's value in this context is not as a witness, but as an interpretive tool.

Another crucial aspect of Abbott's approach is her understanding of photographic technology as essential to the process of grasping the represented subject matter. Finding a relation in these photographs between the image and nature depends on the ability to recognize how photography produces images in reaction to events in the world. Their naturalism then proceeds less from the degree to which the viewer can visually connect them to nature, and more from connections to other photographs. We are not born knowing how photographic technology works or how its products look; we build this knowledge through experience. In the case of the vector image, one must be able to recognize the traces of the photographic process in order to learn the concept at hand. Because of what we know about how light affects film and because of our experience with previous photographic images, if an object appears multiple times in an image we deduce it was possibly made with a strobe flash. We interpret the object as having been in motion and the photograph as relating to a specific length of time. Abbott and her collaborators therefore intentionally and strategically employ a certain level of understanding of photography on the part of the viewers in support of the pedagogical process. The full caption to the vector image in the PSSC asks, "Why do the strings appear

40. Bender and Marrinan, *Diagram*, chapter two.
41. Bender and Marrinan, *Diagram*, 7.
42. Bender and Marrinan, *Diagram*, 6–7.

to be in the foreground?" This question assists students in understanding not just the subject matter, but also the photographic process.[43] The reader is led to surmise that the strings stayed still while the ball moved, and that they were thereby exposed for longer, which is why they appear brighter and closer. Explanations relating to the functioning of photographic technology accompanied instruction on natural laws and presented photography's visual quirks as coherent with a broader explanatory system for physics. The forms visible in the image would not actually convey the intended information if one did not know anything about photography.

Similarly, a caption drafted to accompany a strobe photograph of a ball travelling in an elliptical path helps the viewer think through both the physical laws and the photographic process. "The photo shows a small brass ball swinging in an elliptical path around a central stationary object. The film was exposed at equal time intervals, and the camera was located directly above the plane of the ellipse. A line from the central object to the brass ball sweeps over an equal area between any two successive positions of the ball. This, of course, causes the ball to move more slowly at each end of the ellipse." A subsequent caption suggests that, "with ruler and graph paper you can determine that an imaginary radial line from centre to bob sweeps out equal areas in equal times."[44] This accompanying text is, again, essential, for it is through both text and photograph that the viewer can mentally convert the form made by many iterations of the same brass ball into an understanding of motion. The text not only helps the viewer use their understanding of photographic technology to perform this conversion, it provides parameters that allow the photograph to be used as a diagram. Photography's use of light to create traces of objects on film produces a visualization of a pendulum's motion. This photograph was used in *The Attractive Universe* to discuss planetary motion.[45] | fig. 4 | We can note here certain formal concerns such as a contrast between light and dark, a balanced, geometric composition, and the use of a light source and shading to indicate three-dimensionality. These aspects of Abbott's images often caused them to be framed in an unproductive dichotomy of art versus science, but Abbott was convinced that artistic and scientific concerns intertwined to make pedagogically successful images.

I turn now to a different type of photograph. Abbott's technique of applying photography to wave motion—a principle that describes the behaviour of light and sound as well as subatomic particles—was to clarify what one sees in a ripple tank, a common classroom tool, the use of which the PSSC encouraged. To do this, she adapted the technique of the photogram, in which objects on photosensitized paper are exposed directly to light without the use of a camera. To photograph waves, the paper was exposed while directly underneath a glass tank. | fig. 5 | As with the multiple-flash images, in the photograms Abbott created an image that allowed her aesthetic concerns to cohere with the pedagogical goals and with the principles of regularity in the laws of physics. Abbott strove for a balanced composition, crisp focus, and a play between light and dark. These qualities do not appear when we look at a ripple tank; they are only visible in the photographs. Furthermore, Abbott printed the images in negative. Accompanying texts explained the photographic process so that the viewer knew exactly how to use the information

43. *Physics*, 83.
44. These are two of a series of draft texts held along with Abbott prints in the Photography Collection, Miriam and Ira D. Wallach Division of Art, Prints and Photographs, New York Public Library.
45. E.G. Valens, *The Attractive Universe* (Cleveland, 1969), 43.

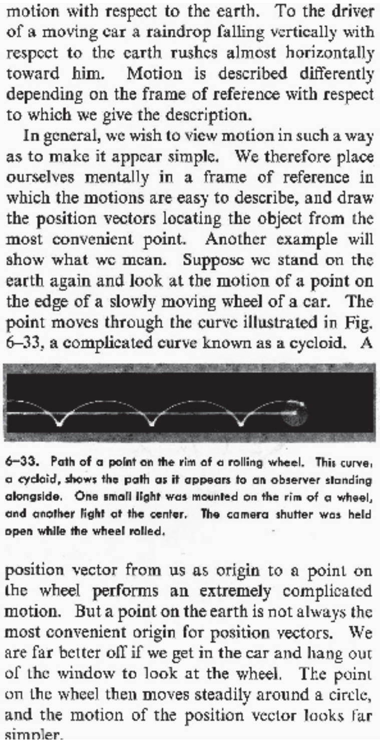
that appeared in the image in order to treat the photograph as a diagram of the results of a ripple tank experiment. Students were taught to observe the ripples visible in the photographs in order to learn about various laws.[46]

Another image used in the 1960 PSSC *Physics* text shows a cycloid (a type of curve resembling a series of arches), in a section of the book that explains the idea of "frames of reference" in order to analyze motion with vectors.[47] | fig. 6 | Here we see a wheel, to which a light has been attached, that is rolling as if along a road. The light draws an arcing path. The text explains that if the frame of reference (meaning the position of the camera and the edges of the photograph) for viewing this wheel were from inside a car attached to the wheel, then a simpler, circular path of motion would be drawn. As the text explains, vectors are specific to their points of origin. This piece of information is crucial for understanding Copernicus's observation that the simplest way to describe the motion of planets through measuring vectors is with their point of origin as the sun instead of the earth. The camera stands in for the point of origin or the "mental" frame of reference. Photography thus becomes a central part of the educational process.

In *The Attractive Universe* Abbott explored another strategy for photographic indication of motion. Instead of a strobe exposure, she created some images using one long, time-lapse exposure. Instead of appearing as discrete points, the moving ball appears as a continuous blur, a solid, golf ball-textured line.[48] | fig. 7 | Speed is here represented by the density of the line, and not by the distance between separate images of balls or points that make up the paths. In order to understand the photograph, one must again be able to recognize the visual signs of a photographic process. A fainter line indicates faster movement, and a more solid line indicates slower movement. Density could, theoretically, be measured and used to calculate speed. The fact that objects in motion can appear blurry on film depending on the duration of exposure is deliberately employed as illustrative. This strategy is once again only intelligible if one has previous knowledge of the conventions of photography. Abbott used a similar method in *Magnet*. In a photograph of a hanging magnetic bar held by a string above a compass, two prominent blurs in the shape of pie slices indicate the movement of the magnet, which wavers back and forth before settling on the north-south axis. | fig. 8 | The text explains, "the magnet will spin slowly back and forth—as we can see from the blur in the photograph—until it finally comes to rest pointing north-and-south."[49] A shape thus appears on the film that has no existence apart from the film. The photograph's ability to serve as truthful record is completely separate from visual similitude, and operates based on a set of learned conventions.

In *Magnet*, an array of white markings on a black background is featured on a double-page spread. | fig. 9 | The caption explains, "a desert of iron filings is sculpted into a beautiful design by the presence of a magnet."[50] For this photograph, Abbott pointed her camera directly downward at iron filings that rested on a flat surface under which was placed a magnet that was powerful enough to move them into alignment. She then printed the image in negative. Magnetism, as a non-visual property or principle, is thus given a visible shape through photography, and again, knowledge of specific photographic processes enables a connection to be forged between photograph and world,

46. *Physics*, 177, 271, and back cover.
47. *Physics*, 90.
48. Valens, *Attractive Universe*, 27–28.
49. E.G. Valens, *Magnet* (Cleveland, 1964), n.p.
50. Valens, *Magnet*, n.p.

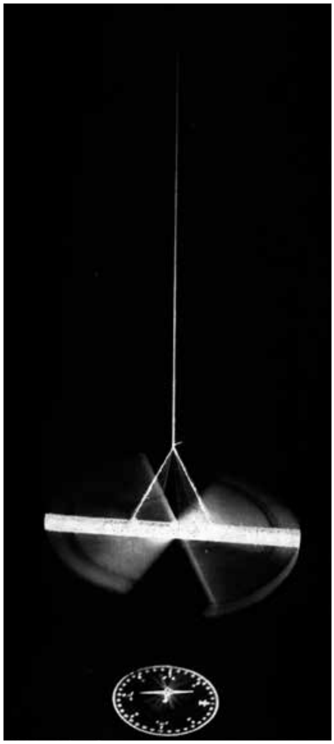


motion with respect to the earth. To the driver of a moving car a raindrop falling vertically with respect to the earth rushes almost horizontally toward him. Motion is described differently depending on the frame of reference with respect to which we give the description.

In general, we wish to view motion in such a way as to make it appear simple. We therefore place ourselves mentally in a frame of reference in which the motions are easy to describe, and draw the position vectors locating the object from the most convenient point. Another example will show what we mean. Suppose we stand on the earth again and look at the motion of a point on the edge of a slowly moving wheel of a car. The point moves through the curve illustrated in Fig. 6–33, a complicated curve known as a cycloid. A

6–33. Path of a point on the rim of a rolling wheel. This curve, a cycloid, shows the path as it appears to an observer standing alongside. One small light was mounted on the rim of a wheel, and another light at the center. The camera shutter was held open while the wheel rolled.

position vector from us as origin to a point on the wheel performs an extremely complicated motion. But a point on the earth is not always the most convenient origin for position vectors. We are far better off if we get in the car and hang out of the window to look at the wheel. The point on the wheel then moves steadily around a circle, and the motion of the position vector looks far simpler.



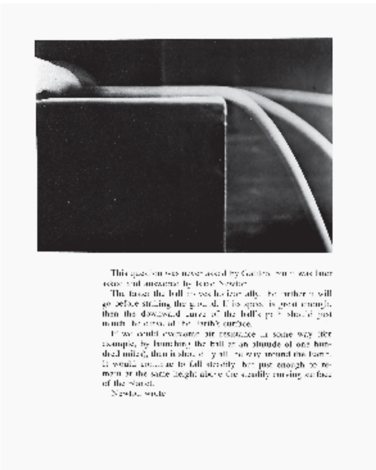


Figure 6 (above left). Physical Science Study Committee, *Physics* (D.C. Heath, 1960), 90.

Figure 7 (left). E.G. Valens and Berenice Abbott, *The Attractive Universe* (Cleveland: World Publishing Company, 1969), 28.

Figure 8 (above right). E.G. Valens and Berenice Abbott, *Magnet* (Cleveland: World Publishing Company, 1964), n.p.

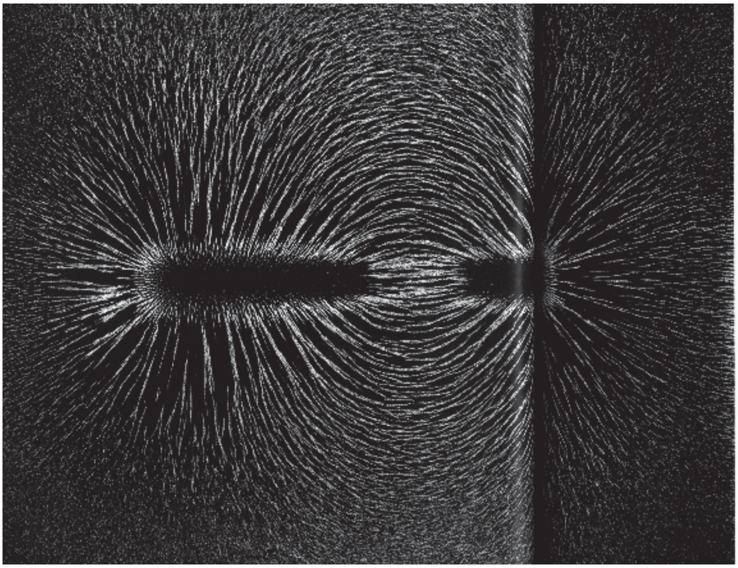
one that would not exist if the viewer did not understand exactly how camera and film are used.

A photograph of a spinning wrench, an image that demonstrates the principle of the centre of mass remaining stable as an object rotates, appeared both in the PSSC textbook and in *The Attractive Universe*.[51] | fig. 10 | As in the above cases, the subject is a specific property of objects in motion: the displacement of the centre of mass of an object in relation to the movement of the object as a whole. The photographic process results in an image in which points on the print represent points in the path of motion of the object but are rearranged into an image of the principle at hand. Black crosses mark the centre of the mass of the wrench (towards the top of the handle) and cue the viewer to seek out the explanatory text that will give the crosses meaning. In turn, the text leads the viewer to understand the image as resulting from the wrench's motion. A caption drafted for this photograph's display in the Smithsonian travelling exhibition includes the explanation, "A ruler laid across the photograph lines up the cross on the handle in a straight sequence. The law expressed is that of constant velocity."[52] In other photographs, numbers or rulers were actually included in the photographic image, as we see in an image on gravity.[53] | fig. 11 | Further numerical information and text is required for the image to do its pedagogical job, but the numbers and lines that actually appear in the photograph both cue the reader to its use and provide some of the constraints with which points in the image can be used in calculations.

I have argued that Abbott's images call into question the assumption that scientific representation is defined by a version of naturalism that involves the suppression of detectible mediation or intervention. Her scientific photographs function not on the basis of visual similitude to the natural world or of effacement of representational convention, but rather on the viewer's previous experience of photographic images and his or her conscious comprehension of the photographic process. The viewer is thus able to access the image as a diagram and use it to understand physical laws. What becomes apparent is that visual and verbal cues are both necessary for science and embedded in conventions of representation. Abbott's images are able to communicate their subject matter because they mobilize the viewer's understanding of photographic technique. This knowledge is based not only on other photographs the viewers may have seen, but also on the textual parameters that are set alongside the images. The accompanying text and captions provide information about processes that transform the marks and forms into signs of the technological steps that created the image. The images thus rely on the viewer's understanding of how photography works in order to convey knowledge of the natural world.

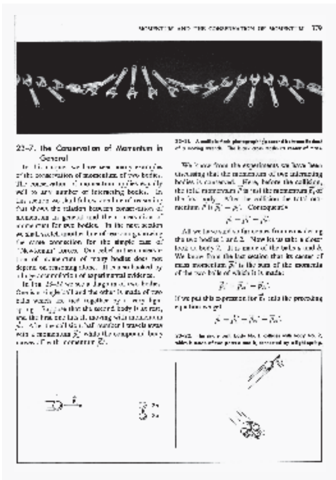
Abbott's scientific work commits itself strongly to a physical relationship between natural phenomena and photographic technology, but one that has hitherto evaded analysis, partly because of our long-standing reliance on indeterminate categories for representation. In accounting for photography's utility by referring to its direct reproduction of what occurs before the lens, we lose sight of how pre-existing knowledge of photographic processes, diagrammatic constraints, and conventions of representation allow these

51. *Physics*, 379, and Valens, *Attractive Universe*, 109.
52. Smithsonian Institution Archives, Record Unit 290, Smithsonian Institution, Traveling Exhibition Service, Records.
53. Valens, *Attractive Universe*, 12.



Here a desert of iron filings is sculptured into a beautiful design by the presence of a magnet. Each shred of iron becomes a tiny magnet as long as the large magnet is nearby. The filings have lined up like little trains of magnetic flatcars, the north pole of one fleck of iron clinging to the south pole of the next.

What we see in the photograph is part of a *magnetic field*—the region around the magnet in which magnetic forces can be detected. The lines of force that loop out from both poles show us the shape of the field. They are real only in the sense that the paths of falling raindrops—which we might call "gravitational lines of force"—are real.



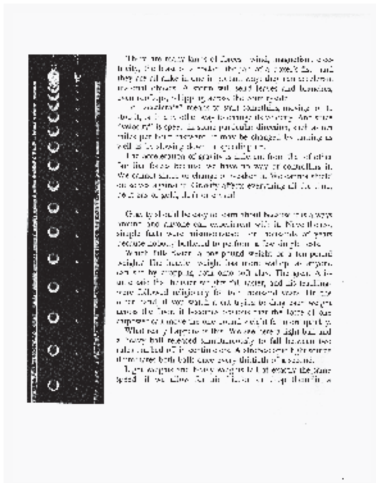


Figure 9 (above). E.G. Valens and Berenice Abbott, *Magnet* (Cleveland: World Publishing Company, 1964), n.p.

Figure 10 (right). Physical Science Study Committee, *Physics* (D.C. Heath, 1960), 379.

Figure 11 (far right). E.G. Valens and Berenice Abbott, *The Attractive Universe* (Cleveland: World Publishing Company, 1969) 12.

images to be pedagogically useful. Scientific principles appear in a specifically photographic form that works as one piece of a broader explanatory system. Furthermore, the photographs' ability to function as diagrams securely roots them in a relationship with knowledge about the world that is based on the productive qualities of mediating, conventional components. It should be clear by now that mediation and conventionality in no way suggest falsification, and that the presentation, rather than re-presentation, of data has been a job for photography throughout its history. I refer again to Abbott's oft-repeated sentiment:

> Contrary to the idea of many, photography is not an involuntary reflex, like the heart beating or the lungs' breathing. It is the product of centuries of investigation, culminating in the creation of a machine and a method with unique capacities for making pictures. But only when the machine and the method are guided by a human being can the photograph be made. In the widest sense, human intelligence creates photography.[54]

Abbott believed that for people to feel connected to and motivated by scientific knowledge, this knowledge had to be visually portrayed in a compelling way, and that photography was "preeminently qualified to unite art with science."[55] In Abbott's process for these photographs, artistic and pedagogical goals were realized though the same means. She fought as hard for their circulation in museum exhibitions as she did for their publication in textbooks. They were not meant to operate solely in the art world nor exclusively in the scientific one, and thus illuminate the disciplinary assumptions of both spheres. In the PSSC textbook, it is not indicated which photographs are Abbott's, nor is it made clear that she had certain formal requirements such as smooth arcs, high contrast, sharp focus, or a specific composition that situated objects in an abstracted space. In contrast, when the images appeared in exhibitions or in art books, Abbott's formal goals and techniques were emphasized, but scientific information was reduced. In the general-audience science books, it is perhaps easiest to see how Abbott intended the images to function, as her authorship of the photographs is made clear, and the images are a large and prominent part of the layout.

Abbott looked for ways to make photographic technology serve the idea being taught. In working on these books, she and her colleagues employed photography both to improve viewers' abilities to understand the medium itself and to teach science. They used the concepts being taught to bolster photography's status as a representational tool at the same time as they drew on the intelligibility of photography to their audience. The photographs relied on the precedent of other images to be successful in their pedagogical role. In addition, Abbott's photographs visualized natural phenomena that are not inherently visual, and in doing so, generated rather than illustrated the data being analyzed. Abbott's work demonstrates how the concept of naturalism can be problematic as an explanation for photography's authority, and how scientific representation is shaped by conventions of visualization. ¶

54. Abbott, *Guide to Better Photography*. In an interview for a WPA radio program called "Exploring the Arts and Sciences" in 1939, Abbott stated that "contrary to popular superstition which says that photography is a simple mechanical affair, actually it is the least mechanical of mediums." Abbott NYPL, folder 9.7, page 7.

55. Berenice Abbott, "The Image of Science," *Art in America* 47 (1959): 76.