Part III. Operationalism and Its Changing Social Environment

Chapter 7. Bridgman, War, and Freedom in Science

When considering the relation between science and operations, one may probably think of the industrial and military applications of science as examples that represent the operational aspect of science most clearly. Nevertheless, throughout his analysis of physical theory, Bridgman remained concerned only with the operational definability of physical concepts and never mentioned the technological applications of science. I have discussed that Bridgman never attempted to define or detail the concept of operation partly because his belief that the goal of scientific activity was the acquirement of knowledge of nature prevented him from paying attention to its practical aspect. The same inclination of Bridgman may possibly have caused his disregard of the industrial and military implications of science in his philosophical work: he did not discuss the technological applications of science probably because he was not interested in what science could do or did outside scientists' academic concern. However, by scrutinizing his argument more closely, one may come to interpret this feature of his operational analysis in a different way.

In his discussion of dimensional analysis in the 1930s, Bridgman admitted that "the experience of all the ages" had selected the suitable concepts to describe physical reality, such as length, mass, and time. Later in 1950, he reiterated that it took long experience to find the operations for measuring those physical quantities. This seems to suggest a possibility that Bridgman may have recognized the social and historical origin, though not implications, of science. Furthermore, through his daily experiment he knew how heavily his experimental work depended upon contemporary industrial technology. However, again, as the previous chapters have shown, Bridgman never took interest in investigating further the socio-historical origin of physical concepts or the relation between experimental science and technology.

In his scrutiny of physical theory Bridgman expressed little concern with the relation between science and society. Even when it appeared appropriate or necessary to mention this matter, he gave it almost no consideration. As will be discussed later, Bridgman was courageous enough to apply operational analysis to social issues, but never explored the question of, for instance, the function or social legitimacy of science.

Bridgman's apparent disregard of the social aspect of science does not mean that he had only a faint idea about the relation between science and society. On the contrary, his several comments on this matter clearly show that he had a firm belief concerning the position of science in society. Probably this belief was so strong and seemed so obvious to him that he seldom saw the necessity to address it, unless something urged him to do so. And, as will soon be shown, only war created such situations in which he had to express it, in word and deed. Thus, by examining Bridgman's addresses and activities during World War II, one may be able to obtain a clue to understanding why he never detailed the social function and status of science.

In the following, I will discuss Bridgman wartime addresses and essays and will try to clarify his recognition of the relation between science and society, in order to understand how his firm belief in the social legitimacy of science formed limitation of his philosophical scrutiny of science. Together with this, I will detail his attempts to apply operational analysis to social concepts and examine the origins and grounds of his belief that science was private.

7.1. Society and Scientists' Struggle for Intellectual Integrity

Bridgman was willing to offer his expertise for wartime problems when he saw it necessary. In the beginning of World War I, Bridgman voluntarily gave suggestion to the Navy on the construction of guns.[1] The Navy did not adopt this idea but later asked Bridgman to work on anti-submarine devices. He accepted this task and continued to work at the Naval Experimental Station at New London, Connecticut, even after the war was over.[2] However, when the Navy requested him to file an oath of secrecy in 1919, Bridgman wrote to Captain J. R. Defrees about his unwillingness to take the oath: "I do not like the imputation that my sense of the requirements of the situation is not sufficient to ensure the correctness of my behavior, and that any such mere formality as going before a notary and holding up my right hand is any more likely to make me act in the way which I should."[3] He did not hesitate to reveal his antipathy toward the bureaucratic conditions of military research.

Almost two decades later, in his systematic attempt to analyze social concepts, Bridgman explained why he found no value in exacting an oath from someone. "By its very nature," he wrote, "an oath can have binding force only on one who accepts the premises back of the idea of oath."[4] However, as no one can tell whether the swearer accepts the premises or not, or whether the swearer lies or not, the oath has no value. This was one of the typical consequences of Bridgman's operational analysis of social institutions.

After seeing his analysis in *The Logic of Modern Physics* succeed to

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[1] P. W. Bridgman to A. G. Webster, Oct. 26, 1915, PWBP, HUG 4234.8.
[2] P. W. Bridgman to C. E. Monroe, Jan. 19, 1919, PWBP, HUG 4234.8.
[3] P. W. Bridgman to J. R. Defrees, March 23, 1919, PWBP, HUG 4234.8.
[4] P. W. Bridgman, *The Intelligent Individual and Society* (New York: The Macmillan Company, 1938), p. 244.

some extent in clarifying the meaning of physical concepts, Bridgman attempted to point out the implications of the uncertainty principle for "a man in the street" ("The New Vision of Science," 1929), described the growing influence of basic research upon industrial and military technology ("The Physicist Today,"[5] 1931), and finally ventured to analyze social questions in the same way as he had discussed scientific matters ("The Struggle for Intellectual Integrity,"[6] 1933). As the above example of an oath shows, however, he immediately found many social institutions incompatible with intellectual integrity that he had been living with, integrity that scientific activity demanded and exemplified.

In "The Struggle for Intellectual Integrity," published in *Harper's Magazine*, Bridgman pointed out that intellectual integrity that had recently been spreading in the community caused and demanded changes in the contemporary community, such as the change in the younger generation's attitude toward religion. The prevailing intellectual integrity, he wrote, had led the younger generation to feel that the teachings of the conventional religion were simply "not 'true', to express it very crudely."[7]

In Bridgman's observation, the immediate cause for this increase of intellectual integrity was the influence of science upon society brought about by "the recent growing prevalence of scientific education, the popular dissemination of the results of scientific inquiry, and the presence in the community of a body of men actually engaged in scientific work."[8] He did not deny that intellectual workers in fields other than science lacked intellectual honesty; yet he asserted that in

[5] P. W. Bridgman, "The Physicist Today," *Harvard Graduates' Magazine*, March 1931, pp. 289-297.
[6] P. W. Bridgman, "The Struggle for Intellectual Integrity," *Harper's Magazine*, Dec. 1935; Reprinted in P. W. Bridgman, *Reflection of a Physicist* (New York: Philosophical Library, 1955), pp. 361-379.
[7] *Ibid.*, p. 362.

scientific activity the insistent necessity for "continual checking against the inexorable facts of experience" and the immediate penalties for "allowing the slightest element of rationalizing to creep in" taught "the dullest" that "a high degree of intellectual honesty is the price of even a mediocre degree of success."[9] Furthermore, Bridgman emphasized a "strong emotional appeal" of this intellectual honesty: scientists cherish "the selflessness involved in rigorously carrying through a train of thought careless of the personal implications"; they feel "a traitor to something deep within [them] if [they] refuses to follow out logical implications because [they see] that they are going to be unpleasant"; and they exult to belong to "a race which is capable of such emotions."[10]

To Bridgman, scientists' intellectual integrity appeared to be "the last flowering of the genius of humanity, the culmination of a long cultural history, and the one thing that differentiates man most notably from his biological companions."[11] Bridgman therefore admitted no limitations to scientific research: "man would be a traitor to himself if he refused to follow his mind wherever it leads him."[12] Aware of the antiscientific mood after the Great Depression, however, Bridgman did not expect society to approve his vision totally. He heard that some critics ascribed much of the economic trouble to invention and scientific discovery that had come too rapidly to be assimilated. Furthermore, they seriously suggested suspending scientific inquiry until human institutions had caught up. Bridgman repudiated their suggestion as "impossible": "we feel that we cannot accept the imposition of limitations to mental inquiry; that we must carry on no matter where it

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[8] *Ibid.*, p. 365.
[9] *Ibid.*, pp. 365-366.
[10] *Ibid.*
[11] *Ibid.*, p. 366.
[12] *Ibid.*, p. 367.

leads."[13]

People with an appreciation and capacity for such intellectual integrity would find society "an utterly inchoate mess" subject to no conscious or rational control, since "[s]ocial institutions have a history as long as that of mankind itself," "have evolved with it," and "contain the reminiscences of the great episodes through which the human race [...] has passed." [14] Therefore, as the change in the younger generation's religious attitude showed, the prevalence of intellectual integrity caused the whole community to drift and flounder morally, though Bridgman judged that "a decline in apparent morality would be the necessary prerequisite to a general advance."[15]

Bridgman went on to warn that the practice of intellectual integrity could conflict with traditional conventions. For example, people free from "mysticism" would regard death as "no calamity"; "for death itself is not experienced, but it is only the preliminaries of death which are experienced and to be dreaded."[16] It is completely rational that if "one found oneself in such a situation that the probable future held more pain than pleasure, one should immediately find the way out by suicide."[17] Admitting that this example could be too drastic, Bridgman imagined that the class of the community holding intellectually honest but unconventional views might be eliminated, as the "essential tragedy of Germany at present moment" [18] showed. Even if they are not eliminated, it is not "self-evident" "whether in the present setting the human intellect is powerful enough to grapple with the enormous

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[13] *Ibid.*
[14] *Ibid.*
[15] *Ibid.*, p. 370.
[16] *Ibid.*, p. 371.
[17] *Ibid.*
[18] *Ibid.*, p. 372.

complexities of the situation."[19] However, Bridgman saw no possible course except to carry on with the belief that "under the proper conditions the human intellect is capable of designing a rational society capable of self-preservation."[20]

Accepting that the first stage of the rational reconstruction of society might be "purely destructive,"[21] Bridgman tried to show how the next stage would be by describing the similar problems physics had been facing. Physics had undergone a period when its traditional concepts, such as space, time, causality, and identity, could no longer deal with the new situations created by the accumulation of experimental knowledge. Physicists then had had to devise new ways of thinking and, furthermore, examine the nature of human thinking. In so doing, Bridgman asserted, physicists had realized that "thinking is merely a form of human activity, performed with the brain, subject to the limitations of its evolution and its origin of production, and with no assurance whatever that an intellectual process has validity outside the range in which its validity has already been checked by experience."[22] To Bridgman, the parallelism between this experience of physicists and recent social developments was obvious: As physics underwent a drastic transformation in the face the accumulation of new experimental results, society should change in the "absolutely new situation," presented by "the development of labor-saving devices," "the World War with the unwilling entry into it at last of the United States, the peace and the failure of Wilsonian idealism, the League of Nations, the economic aftermath of the War, boom, depression, the return of economic nationalism, Mussolini, Russia, Germany and Hitler, Japan

[19] *Ibid.*, p. 373.
[20] *Ibid.*
[21] *Ibid.*
[22] *Ibid.*, p. 374.

and Manchuria, Gandhi in India, the loosening of the British Empire, would congresses for peace and economics, woman suffrage, the rise and fall of prohibition, and the voluntary economic revolution in the United States."[23] Bridgman expected that this new situation would influence social thinking in the same way as the discovery of new physical phenomena affected physicists' way of thinking. Naturally, he did not forget to mention that his operational way of thinking would be useful: as Einstein's "insistence on the realistic nature of the concepts of physics" in his relativity theory showed, "the true significance of a physical concept is not to be found in what we say about it or even in what we think about it, but rather in what we do with it."[24] Though he could conclude nothing definite, Bridgman at least showed how to apply operational analysis to social concepts.

In 1938, Bridgman boldly went on to publish his more thorough social analysis in a book *The Intelligent Individual and Society*[25] and in an article "Society and the Intelligent Physicist."[26] By then he had noticed that those who were disappointed that the Utopia promised by technological advance did not come easily started to mention the possibility of the "bankruptcy"[27] of science. However, believing that "science was never less bankrupt than at the present time," Bridgman had become even more confident than he was in "The Struggle for Intellectual Integrity" that "in the experience of physics of the last few years" one could find illuminating suggestions for the complex social

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[23] *Ibid.*, p. 375.
[24] P. W. Bridgman, "Intellectual Integrity," pp. 376-377.
[25] P. W. Bridgman, *The Intelligent Individual and Society* (New York: The Macmillan Company, 1938).
[26] P. W. Bridgman, "Society and the Intelligent Individual," *American Physics Teacher*, 7 (1938), pp. 109-116; reprinted in P. W. Bridgman, *Reflection of a Physicist* (New York: Philosophical Library, 1955), pp. 380-402 (Citations are from the latter). Bridgman delivered this address at the eighth annual meeting of the American Association of Physics Teachers in Washington in December 1938.
[27] Bridgman, *The Intellectual Individual and Society*, p. 10.

situation.[28] Most of Bridgman's discoveries concerning social matters remained almost the same as five years before: He still found many practices and demands of society "positively inimical to the exercise of intelligence."[29] Yet, in 1938, observing the growing anti-intellectual tendency in the totalitarian states, he started to elaborate the foundations of his reasoning and tried to advocate intellectual freedom of scientists by clarifying what he believed to be essential to scientific activity.

In *The Intelligent Individual and Society*, Bridgman clearly stated his solipsistic interpretation of intellectual integrity: "Operationally there are two kinds of honesty as there are of practically every other personal characteristic: honesty toward others and honesty toward myself. It is the latter that is primarily concerned in intellectual honesty."[30] Upon those who try to be intellectually honest, "[n]o one can force his authority [...] until [they] have recognized his right to authority."[31] Even symbolic logic, for example, is not absolutely valid to them: "The concept of validity is meaningless until I have made the logic live by my vision and my acceptance."[32] Another example was perhaps something similar to what had actually happened to him: "The voice of God which I am told speaks to me directly through my conscience with an authority that cannot be evaded is no more than a babbling brook and not the voice of God until I have accepted it to be the voice of God." In their requirements of unquestioning allegiance, therefore, "Stalin and Mussolini and Hitler" failed to recognize the necessity of prior acceptance of their authorities by each individual.[33]

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28 *Ibid.*, pp. 10-11.
29 Bridgman, "Society and the Intelligent Physicist," p. 388.
30 Bridgman, *The Intelligent Individual and Society*, p. 261.
31 *Ibid.*, p. 156.
32 *Ibid.*
33 *Ibid.*, pp. 156-157.

In December 1938, Bridgman addressed to his fellow physics teachers:

> Although Hitler may be right in following his own drives in the face of the abhorrence of a large part of his fellows, he is dead wrong if he thinks that an intelligent society can be created by suppressing the individual and turning the world into a human ant heap. An intelligent society has got to start with the individual and end with the individual. Nothing else makes sense.[34]

One of the derivatives of Bridgman's conviction of the priority of individual intellectual integrity was his antipathy toward totalitarianism.

Bridgman's reflection over intellectual integrity supported his belief that "science is private." He admitted that science was defined to be "that body of activity by scientists which is universally accepted as valid by all those competent to judge."[35] Nevertheless, he regarded his criteria and judgments of validity as "entirely apart from what [his] fellows say." Though "as a matter of experience" he had found that he was least likely to be making mistakes when his conclusions agreed with those of his fellows, "securing the consensus of opinion of my fellows in this way is something that *I* do for reasons that *I* have accepted."[36] Or, "I stand alone in the universe with only the intellectual tools I have with me."[37] Bridgman therefore contended that physics, mathematics, or any other science was his private science since the criteria of its validity were ultimately his own private criteria: "*My* science is operationally an entirely different thing from *your* science,

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[34] Bridgman, "Society and the Intelligent Physicist," p. 402.
[35] Bridgman, *The Intelligent Individual and Society*, p. 157.
[36] *Ibid.*
[37] P. W. Bridgman, "Freedom and the Individual," *Reflection of a Physicist*, pp. 62-80, p. 79; originally in Ruth Nanda Anshen, ed., *Freedom: Its Meaning* (New York: Harcourt, Brace and Company, 1940), pp. 525-537).

as much as *my* pain is different from *your* pain."[38] On another occasion, he gave a more detailed explanation to the same conclusion.

> The process that I want to call scientific is a process that involves the continual apprehension of meaning, the constant appraisal of significance, accompanied by a running act of checking to be sure that I am doing what I want to do, and of judging correctness or incorrectness. This checking and judging and accepting, that together constitute understanding, are done by me and can be done for me by no one else. They are as private as my toothache, and without them science is dead.[39]

Feeling great difficulty in making his point that "science is essentially private," Bridgman knew that his contemporary scientists did not always share his view and usually only judged that "confirmation or verification by their individual selves is superfluous." This, Bridgman lamented, was "as natural an attitude in a society committed to the virtue of democracy as in one committed to totalitarianism."[40] Bridgman's advocacy of intellectual integrity and private science resulted in not only his antipathy toward totalitarianism but also his doubt about the intellectual durability of the society in which he lived.

Judging that scientists' intellectual integrity was far more trustful than social institutions and conventions, Bridgman admitted a privileged social status for scientists: He did not allow society to fix any responsibility on scientists. Little appeared more important to Bridgman than that the individual scientists should enjoy opportunities to find and to record wherever their mind took them, "irrespective of

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[38] Bridgman, *The Intelligent Individual and Society*, p. 158.
[39] P. W. Bridgman, "Science: Public or Private?" in *Reflection of a Physicist*, pp. 43-61, p. 50. Originally in *Philosophy of Science*, 7 (1940), pp. 36-48. Bridgman read this paper at the Fifth International Congress for the Unity of Science in Cambridge, Massachusetts on September 4, 1939.
[40] *Ibid.*, p. 46.

consequences."[41] He maintained that a responsibility for preventing the misuse of scientists' inventions belonged to society, not scientists.

Meanwhile, seeing the growing tensions in Europe and East Asia, Bridgman discussed the exercise of force and war from the physicist's point of view. He understood that physicists had little inclination to apologize when they accepted "the naturally imposed necessity to use force to secure desired results in certain situation,"[42] since they were specialists in adapting themselves to the world around them. To him, it was obviously one of the "inescapable properties of the world in which we live" that people were "powerless in the face of overwhelming physical force," or that "[t]here is no argument with an exploding bomb."[43] Though he admitted that this fact was an unwelcome human limitation, he pointed out that the objection to the use of force might be just "an esthetic one." In Bridgman's understanding, those who might feel the exercise of force so repugnant that one would rather submit to any indignity than use it were only "poorly equipped to face the world."[44] To him it appeared as great "a calamity" to refuse the exercise of force unconditionally as it was to feel that eating was "a horrid physical thing": some might feel it disgusting to open their mouths and put things into them, but feeling this way only meant "either starvation or constant nausea at the necessity of having to eat."[45]

Furthermore, Bridgman argued that ethics and moral were not effective enough to stop the use of force in its greatest extremes: he recognized it "just plain silly and evidence of crooked thinking" to attempt to "set up codes of conduct of war by appealing to moral or

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[41] Bridgman, *The Intelligent Individual and Society*, p. 250.
[42] Bridgman, "Society and the Intelligent Physicist," p. 400.
[43] *Ibid.*, p. 399.
[44] Bridgman, *The Intelligent Individual and Society*, p. 165.
[45] Ibid., p. 165.

ethical feelings, unless there is somewhere in the background a force to secure observance of the code if necessary," since war was "that manner of conduct which discards all sanctions except force."[46]

> Logically war is that method of conduct which recognizes no limitations whatever, and to try to control it by rules involves a self-contradiction. No nation, if it carries things to their consistent conclusion, is going to forego any advantage in war which it thinks it can get away with, that is, which it thinks will not sometime call into action superior force of one sort of another. The righteous indignation of the civilized world at the submarine or poison gas is just evidence of fuzzy thinking.[47]

Although Bridgman observed that such weapons as the submarine and poison gas that science had created had made war far more destructive and disastrous than before, he maintained that no sanction would work to prevent any nation from adopting unethical but more effective arms.

In his reflections over social issues published in the late 1930s, Bridgman recognized war as a possible means that society should take in certain situations and assumed that nations at war would find no limitations in seeking for ways for winning it. Though he knew that science and scientists could make war more destructive than before, he was reluctant to fix a responsibility for the misuse of science upon scientists since he recognized freedom in science inviolable. As will be shown, his views of the social status of science and scientists would remain surprisingly unchanged even after the bombing of Hiroshima and Nagasaki. *The Intelligent Individual and Society*, which Bridgman evaluated important "not for the problems it solves but for the problems it poses,"[48] would continue to be his "particular pet" even in the 1950s, though it had not attract as much attention as he expected.

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[46] *Ibid.*, p. 166.
[47] *Ibid.*

7.2. Bridgman's Fight for Freedom in Science

7.2.1. Bridgman's "Manifesto"

In the late 1930s, while Bridgman publicly addressed his antipathy toward totalitarianism, he also expressed in his private correspondence his distaste for limitations to scientific activities imposed by any governmental, military, or social authority. In April 1938, when Taneo Taketa, Manager of the South Manchuria Railway Company, asked Bridgman to have an interview with Assistant Director of his company's Central Laboratories, S. Takashima, during his stay in America, Bridgman declined the request for the following reason:

> Although you say that the laboratory with which he is connected is concerned with research in pure and applied sciences, it seems to me almost inevitable that the results of any such research conducted by a railway company will be used in furtherance of the Japanese program of the exploitation of China. This whole activity on the part of Japan is so abhorrent to me that I shall seize every opportunity to express my sentiments on the subject and must, therefore, refuse to take any part which might by any possibility have any connection with it, and must, therefore decline even such an apparently innocent thing as an interview with Mr. S. Takashima.[49]

Bridgman declined the request mainly because of his protest against Japan's exploitation of China. Yet, at the same time, he explicitly stated his doubt about the independence of scientific research conducted in the totalitarian states.

In early 1939, Bridgman decided to close his laboratory to citizens of totalitarian states and handed to visitors a manifesto describing the

[48] P. W. Bridgman to Willis R. Whitney, Dec. 27, 1951, PWBP, HUG 4234.10.

reasons, which he published in *Science* on February 24, 1939:

> I have decided from now on not to show my apparatus or discuss my experiments with the citizens of any totalitarian state. A citizen of such a state is no longer a free individual, but he may be compelled to engage in any activity whatever to advance the purposes of that state. The purposes of the totalitarian states have shown themselves to be in irreconcilable conflict with the purposes of free states. In particular, the totalitarian states do not recognize that the free cultivation of scientific knowledge for its own sake is a worthy end of human endeavor, but have commandeered the scientific activities of their citizens to serve their own purposes. These states have thus annulled the grounds which formerly justified and made a pleasure of the free sharing of scientific knowledge between individuals of different countries. A self-respecting recognition of this altered situation demands that this practice be stopped. Cessation of scientific intercourse with the totalitarian states serves the double purpose of making more difficult the misuse of scientific information by these states, and of giving the individual opportunity to express his abhorrence of their practices.
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> This statement is made entirely in my individual capacity and has no connection whatever with any policy of the university.[50]

Bridgman believed that totalitarianism prevented the free pursuit of scientific knowledge. He maintained that scientists could freely exchange their knowledge because they, sharing the belief that scientific knowledge was sought for its own sake, were free from any other authority than science. Not only because he feared the results of his research to be used for these countries, but also because he regarded these states' citizens as disqualified to participate in scientific communication, Bridgman refuse to receive citizens of totalitarian states in his laboratory. However, he would later see even scientists of "free states" put their duty as citizens before their freedom in scientific

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[49] P. W. Bridgman to T. Taketa, April 7, 1938, PWBP, HUG 4234.10.

[50] P. W. Bridgman, "'Manifesto' by a Physicist," *Science*, 89 (1939), pp. 178-179.

activities.

Upon publishing the manifesto, Bridgman started to receive various responses. A. H. Fraenkel, then the Rector of the Hebrew University, expressed his admiration for Bridgman's attitude.[51] Ellis Freeman at the University of Tampa dedicated his book on psychology of propaganda[52] to Bridgman.[53] The dedication reads: "To Professor Bridgman who knows what can help or hurt science." Max Born expressed his reservation toward the manifesto:[54] "Your Manifesto against the Totalitarians pleases the feelings of my heart, but not quite as much my reason. Would you exclude also men like von Laue, Hahn a. o. who are permanently risking freedom and life by opposing the Nazis in Germany?" Bridgman replied that although he would gladly receive Germans unsympathetic with the Nazi policies, he had not been able to write so since it would make unsafe lives of German visitors to his laboratory when they returned to their home country.[55]

Bridgman found many of his colleagues at Harvard disapprove of his action. Among them, only Harlow Shapley, Director of the Harvard College Observatory, took the trouble to write to him about his "violent disapproval,"[56] though the fear of too messy a publicity prevented him from speaking out.[57] Referring Bridgman to an article in the *Reader's Digest* for March reporting the activities of Germans protesting the Nazi policies,[58] Shapley asked Bridgman to join him in working on the salvaging of "the intellectual victims of fascism." In reply, Bridgman praised Shapley's effort to help intellectual refugees, but expressed his

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[51] A. H. Fraenkel to P. W. Bridgman, March 10, 1939, PWBP, HUG 4234.10.
[52] Ellis Freeman, *Conquering the Man in the Street* (New York: Vanguard Press, 1940).
[53] Ellis Freeman to P. W. Bridgman, May 7, 1939, PWBP, HUG 4234.10.
[54] Max Born to P. W. Bridgman, May 1, 1939, PWBP, HUG 4234.10.
[55] P. W. Bridgman to Max Born, May 27, 1939, PWBP, HUG 4234.10.
[56] P. W. Bridgman to E. Freeman, April 14, 1939, PWBP, HUG 4234.10.
[57] H. Shapley to P. W. Bridgman, Feb. 24, 1939, PWBP, HUG 4234.10.
[58] Edwin Muller, "The Other Germans," *Reader's Digest*, March 1939, pp. 53-58.

estimate of the situation that drastically differed from Shapley's:

> Do you appreciate what a truly monstrous thing is happening before our eyes, or what the implications are of a state that demands the right and sets in motion the means to control the thoughts of all its individual members? If this thing goes on for another ten years, it will be too late—the up-coming generation, including the up-coming scientists and other intellectuals, will be so conditioned that they will be in complete control.[59]

To Bridgman, totalitarianism seemed to be ruining the world, for which the salvation of a few intellectuals would be no compensation.

In his less celebrated but more detailed statement than the "Manifesto," "A Challenge to Physicists,"[60] written at the request of the editor of the *Journal of Applied Physics*, Elmer Hutchisson, Bridgman elaborated what kind of challenge physicists were facing then. He reiterated his belief that a totalitarian victory would mean an intellectual crisis. The fundamental thesis of the totalitarian philosophy, which he described "an intellectual monstrosity,"[61] was that the individual was subordinate to the state. Bridgman observed that the totalitarians were aiming to produce "a society intellectually half slave and half free" in which people were not allowed to "use their minds."[62] What seemed to Bridgman to save the race in this intellectual crisis was "intellectual morale," whose two chief components were "intellectual integrity and a fierce conviction that man *can* become the master of his fate."[63] Bridgman maintained that physicists, who were peculiarly likely to possess these two components of intellectual morale by spending their lifetime in the laboratory and participating in

[59] P. W. Bridgman to H. Shapley, Feb. 25, 1939, PWBP, HUG 4234.10.
[60] P. W. Bridgman, "A Challenge to Physicists," *Journal of Applied Physics*, 13 (1942), p. 209; *Reflection of a Physicist*, pp. 501-503.
[61] *Ibid.*, p. 501.
[62] *Ibid.*, pp. 501-502.

the technological mastery of nature achieved by modern physics, should make others see that "not only is there no substitute for using one's mind, but that the problems which confront us are soluble and soluble by us."[64] He was convinced that this kind of intellectual influence of physicists would "transcend that of any possible technological contribution."[65]

Bridgman never doubted whether physicists could find sufficient reasons for participating in the fight against the totalitarian states. For him, World War II was a war for intellectual freedom that was essential to physicists' pursuit of knowledge. However, to his dismay, he would find his own country that was fighting against totalitarianism start to adopt quasi-totalitarian policies toward scientists and their activities as their roles became more and more crucial in the defense effort.

7.2.2. The President of the American Physical Society at War

In 1942, when America was in the middle of war, Bridgman was appointed President of the American Physical Society, the position that would make him experience the tense relation between scientists and their country at war. While the programs of the academic meetings were passed on by a censorship committee, some papers for the meetings and journals were rejected as being conceivably connected with war problems.[66] Bridgman had to decide not to publish a membership list for that year, since James Conant and Vannevar Bush suggested that the current addresses of the members engaged in war

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[63] *Ibid.*, p. 502.
[64] *Ibid.*, pp. 502-503.
[65] *Ibid.*, p. 503.
[66] K. K. Darrow to P. W. Bridgman, March 25, 1942; P. W. Bridgman to R. S. Ould, Oct. 21, 1942, PWBP, HUG 4234.10.

work were secret.[67] In the winter, another series of events made Bridgman realize that holding an academic meeting during war involved considerable troubles.

The annual meeting of the Physical Society for 1942 had originally been announced to take place at the University of Chicago in the end of the year. However, on October 12, while speakers had already been invited and contributed papers were flowing in, A. J. Dempster, acting Chairman of the Physics Department of the University of Chicago, proposed the Physical Society reduce the annual meeting to a council meeting, as the secret war projects were going on there.[68] He told that the FBI had turned down to bring several physicists of the neighborhood, members of the Physical Society, to the University of Chicago. They were afraid that "enemy agents" might deduce the type of work conducted there from such discussion: "I did not know [Robert] Mulliken was in the Metallurgical Group [at the University of Chicago]. I can understand Fermi and Wheeler being there, but what in the world can Mulliken be doing?" Bridgman did not understand why Dempster took the situation so seriously. Though he also saw very few of the physicists from other places working currently for the secret war projects at MIT or Harvard, he only thought that those who did not wish to have their presence known could simply stay away.[69] However, the Physical Society in the end decided to hold its annual meeting in New York, not in Chicago.

One month later, another problem arose. On November 20, the Director of the Office of Defense Transportation, Joseph B. Eastman, requested a postponement of all meetings involving traveling at the

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67 K. K. Darrow to P. W. Bridgman, Oct. 5, 1942; P. W. Bridgman to K. K. Darrow, Oct. 8, 1942, PWBP, HUG 4234.10.
68 George B. Pegram to P. W. Bridgman, Oct. 14, 1942, PWBP, HUG 4234.10.
69 P. W. Bridgman to G. B. Pegram, Oct. 16, 1942, PWBP, HUG 4234.10.

Christmas holiday period for securing the transportation service for the military.[70] Responding to the request, the American Association for the Advancement of Science decided to postpone its Christmas meeting to the spring or summer[71] and urged the Physical Society to do the same.[72] Bridgman believed that the Physical Society should not lightly cancel the meeting: "I should certainly not be in favor of yielding if the Rosebowl football game is still on and if the travel connected with that is to be permitted."[73] However, the Council of the Physical Society voted to postpone the meeting to sometime in the second half of January.[74] Seeing physics playing a fundamental role in this war, Bridgman suggested the Office of Defense Transportation to issue a statement of the importance of restricting unnecessary travel and to let scientists decide whether they could justify their attendance at meetings from the national point of view.[75] This was as much as he could do.

In his retiring presidential address to the American Physical Society, delivered on January 23 in the New York annual meeting,[76] Bridgman publicly advocated the value of science. Worried about a tendency to maintain that all scientific activities should be under complete supervision and control by society or the state, a tendency that was growing in Russia, England—Bridgman referred to J. D. Bernal's *The Social Function of Science*[77]—, and some quarters in America, Bridgman addressed a view completely opposite to this trend: "Society is the servant of science even more and in a more fundamental

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[70] R. S. Ould to P. W. Bridgman, Nov. 30, 1942, PWBP, HUG 4234.10.
[71] Arthur H. Compton to R. S. Ould, Dec. 3, 1942, PWBP, HUG 4234.10.
[72] K. K. Darrow to P. W. Bridgman, Dec. 4, 1942, PWBP, HUG 4234.10.
[73] P. W. Bridgman to K. K. Darrow, Dec. 1, 1942, PWBP, HUG 4234.10.
[74] K. K. Darrow to P. W. Bridgman, Dec. 2, 1942, PWBP, HUG 4234.10.
[75] P. W. Bridgman to J. B. Eastman, Dec. 12, 1942, PWBP, HUG 4234.10.
[76] P. W. Bridgman, "Science, and Its Changing Social Environment," *Science*, 97 (1943), pp. 147-150.

sense than is science the servant of society."[78] He regarded the guiding motif of science as the craving for understanding, which seemed to him to be one of the things that made the society something more than a mere "vicious merry-go-round."[79] He did not require scientists to be responsible for the results of their discoveries, because he assigned society to provide some mechanism for controlling the results of scientific discoveries, and because he understood that the fundamental condition of scientists' activities was complete freedom, including that from responsibility for the results of their discoveries. In urging these claims on society, Bridgman argued, science would give society return, which he called "the pursuit of truth."[80] Bridgman was afraid that this return might not be sufficient as material benefits, but argued that "it is the one human activity which distinguishes us most from the brutes."[81] He addressed all this while he knew that it was a time when the very existence of society to which he was accustomed was threatened. He even argued that it was the time more than ever to insist that society must conform to the pattern of service to science, and asked, "What are we fighting for anyway?"[82]

7.2.3. War and Freedom in Science

Bridgman received only a few responses to his retiring presidential address, since by then scientists had already started to take actions to support the mobilization of their activities. In the May 1943 issue of the *AAAS* (American Association for the Advancement of Science) *Bulletin*, Bridgman saw a tentative resolution for adoption on support of

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[77] J. D. Bernal, *The Social Function of Science* (London: Routledge, 1939).
[78] Bridgman, "Science, and Its Changing Social Environment," p. 149.
[79] *Ibid.*, p. 148.
[80] *Ibid.*, p. 149.
[81] *Ibid.*

the war effort, prepared by J. B. Conant and others, and sent a severe criticism to its Permanent Secretary, F. R. Moulton. Bridgman did not admit that scientists' current concern was to win the war in the minimum of time. If the war might be won by "the suppression of certain liberties or the abandonment of certain ideals," he estimated, "in the long run it would have been better to have lost than to have won."

> Continual vigilance and criticism is necessary during the conduct of the war to insure against such catastrophes. For this reason, I would be unwilling to give such a blank check as is called for by the final resolution even to God Almighty, to say nothing of our very fallible military leaders.[83]

Bridgman himself had already given up his regular research, devoting himself practically entirely to war work. However, he was doing so in his capacity "as a citizen, not as a scientist." As a scientist, he never let any authority violate his freedom in science.

Bridgman revealed his view of the relation between scientific freedom and duties as a citizen in his letter to Senator Hartley M. Kilgore. On February 11, 1943, Kilgore introduced a bill, entitled "A Bill to mobilize the scientific and technical resources of the Nation, to establish an Office of Scientific and Technical Mobilization, and for other purposes."[84] Strenuously opposing to the bill, Bridgman wrote to Senator Kilgore, the two Senators from Massachusetts, and his Representative in Congress.[85] Bridgman understood that the bill, if enacted, would deprive scientists of scientific freedom, the essential requirement of scientific success, and would virtually constitute an acceptance of the totalitarian philosophy that the individual exists for

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[82] *Ibid.*
[83] P. W. Bridgman to F. R. Moulton, May 23, 1943, PWBP, HUG 4234.10.
[84] "The Mobilization of Science," *Science*, 97 (1943), pp. 407-412.
[85] P. W. Bridgman to F. B. Jewett, June 1, 1943; Bridgman to H. M. Kilgore, June 1,

the benefit of the state. Bridgman asked to protect scientists' right: "The scientist is a citizen as well as everyone else, and he has a right to demand that his Government serve his interest as well as those of his fellows." "If this Bill were enacted," he continued,

> I would feel that I had been made a member of a slave class exploited for the benefit of the majority, and my attitude and actions would become those which are always elicited by the consciousness of exploitation.
>
> My brains are my own. *I* may give them to the State, but the State cannot take them from me.[86]

Bridgman required that the Federal Government allow scientists to enjoy maximum freedom even in emergency, since he regarded freedom as essential to scientific activities. In the end, since many scientific societies opposed to the Kilgore Bill, it was not enacted. By December, Bridgman learned that "the Kilgore Bill is dead" from Shapley, who had become "the world's best authority on the Kilgore Bill" probably in virtue of his position as retiring President of Sigma Xi.[87]

The passion for scientific freedom led Bridgman to take even more substantial political action: publicity and propaganda. In August 1943, having read a report in *Nature* about Bridgman's retiring presidential address at the American Physical Society,[88] Michael Polanyi, then at the University of Manchester, asked for a reprint of the address and informed Bridgman that scientists in Britain including himself had started the Society for Freedom in Science, supporting the same ideas shown in Bridgman's address.[89] Bridgman was excited to learn of his old acquaintance's activity, especially because his colleagues in the

1943, PWBP, HUG 42234.10.

86 *Ibid.*

87 P. W. Bridgman to John Q. Stewart, Dec. 15, 1943, PWBP, HUG 4234.10.

88 "Leadership in a Dynamic Society," *Nature*, 152 (1943), pp. 85-87.

89 M. Polanyi to P. W. Bridgman, Aug. 4, 1943, PWBP, HUG 4234.10.

United States did not seem interested in his presidential address.[90] Three months later, the secretary of the Society, John R. Baker at the University Museum, Oxford, wrote to Bridgman about the Society's history and activities and their earlier attempt to start a sister-society in America that had faded out as the Pearl Harbor attack distracted the attention of their American correspondents.[91] In reply, Bridgman suggested the Society do more publicity in America and take further steps for the solicitation of American members,[92] which, in the end, he did by himself.[93]

Since the beginning of the 1930s, a tendency to overemphasize the material benefits and socially utilitarian aspects of science had been growing in Britain, culminating in the publication of J. D. Bernal's *The Social Function of Science* in 1939 and the activities of the (British) Association of Scientific Workers. Alarmed by this movement, Polanyi published an article "The Rights and Duties of Science"[94] and examined Bernal's discussion. Furthermore, he took initiative in the formation of a new society to promote the causes of pure science and of freedom in science. Thus, the Society for Freedom in Science was established in 1940 by thirty scientists in Britain. However, their society did not acquire much support. When Bridgman introduced the society and the statement of its objects in the July 21, 1944 issue of *Science*,[95] its membership was, after three years of existence, only 134. Baker was grateful to Bridgman's effort, especially because *Nature* had refused to publish even a part of the society's statement, while showing sympathy

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90 P. W. Bridgman to M. Polanyi, Sept., 8, 1943, PWBP, HUG 4234.10.
91 J. R. Baker to P. W. Bridgman, Nov. 4, 1943, PWBP, HUG 4234.10.
92 P. W. Bridgman to J. R. Baker, Dec. 19, 1943, PWBP, HUG 4234.10.
93 P. W. Bridgman, "The British Society for Freedom in Science," *Science*, 100 (1944), pp. 54-57.
94 M. Polanyi, "The Rights and Duties of Science," *The Manchester School of Economics and Social Studies*, 10 (Oct. 1939), pp. 175-193; also in M. Polanyi, *The Contempt of Freedom* (London, C. A. Watts, 1940), pp. 1-26.

with its opponents.[96]

The response to Bridgman's *Science* article was "disappointingly small."[97] Having received only 36 applications for the enrollment by August 14, he estimated that his appeal would result in about 50 enrolments in total, which, though a little too modest, proved to be almost correct, as only 38 enrolments additionally arrived by September 13.[98] Several well-known scientists asked for an enrollment blank: Harry Barton, Director of the American Institute of Physics; Linus Pauling; R. S. Mulliken; and, Sydney Ross and other members of the Department of Chemistry at Stanford University. However, Bridgman's old acquaintance and colleague at Harvard, Harlow Shapley, severely criticized the society and Bridgman's effort.

Before sending the appeal to *Science*, Bridgman showed Shapley the statement of the society. Shapley's "automatic and immediate response" was "that he was against it."[99] Since the statement did not emphasize the social service or responsibility of science, Shapley judged its general tone "reactionary." Eight days after the publication of the statement in *Science*, Bart Bok, an astronomer of the Harvard College Observatory and active member of the American Association of Scientific Workers, sent Bridgman his criticism of the society, which he intended to publish in *Science*.[100] While feeling it unfair to portray the British Association of Scientific Workers as the enemy of scientific freedom as Bridgman and the Society for Freedom in Science did, Bok had to explain that the American Association of Scientific Workers was

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[95] Bridgman, "The British Society for Freedom in Science."
[96] J. Baker to P. W. Bridgman, Aug. 12, 1944, PWBP, HUG 4234.15.
[97] P. W. Bridgman to J. Baker, Aug. 14, 1944, PWBP, HUG 4234.15.
[98] P. W. Bridgman to J. Baker, Sept. 13, 1944, PWBP, HUG 4234.15.
[99] P. W. Bridgman to J. Baker, Dec. 19, 1943, PWBP, HUG 4234.15.
[100] Bart Bok to P. W. Bridgman, July 29, 1944, PWBP, HUG 4234.15. For Bok's scientific and political activities, see, David H. Levy, *The Man Who Sold the Milky Way: A Biography of Bart Bok* (Tucson & London: The University of Arizona Press, 1993).

an organization entirely independent of the British Association. Furthermore, Bok denied necessity for forming an American branch of the British Society, as the existing professional societies, including AASW, would form a sufficient bulwark against any possible encroachment upon freedom in science. In reply, Bridgman wrote that he had no intention to form a branch of the British Society, but did not hide his honest feeling toward AASW:

> I must say, however, that personally I feel that a sufficient fraction of the membership in the AASW has feelings toward Russia of such a kind that the AASW would never be allowed to say publicly the sort of thing that the British Society feels to be necessary in view of the quite uncritical laudation of all Russian science which is now popular in England.[101]

In his letter to Sydney Ross, Bridgman commented on AASW even more explicitly: "[I]t is known that a number of the local members of the A. A. S. W. were formerly active communists and still will permit no criticism of Russia of any sort."[102]

Bridgman knew that Shapley was behind Bok.[103] After *Science* sent a formal refusal letter to Bok, Shapley told Bridgman: "This appears to be an illustration of the Freedom in Science which you have in mind."[104] Several other members of AASW considered the refusal of *Science* to publish Bok's letter as "a dirty violation of scientific freedom"[105] and sent a protesting letter. Moreover, Shapley told Bridgman that he heard that the secretary of the British Society, John Baker, was "a violent anti-Russian."

Meanwhile, the editor of the *Free World*, Blodwan Davies, informed

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[101] P. W. Bridgman to Bart Bok, Aug. 1, 1944, PWBP, HUG 4234.15.
[102] P. W. Bridgman to Sydney Ross, Oct. 23, 1944, PWBP, HUG 4234.15.
[103] P. W. Bridgman to J. Baker, Sept. 13, 1944, PWBP, HUG 4234.15.
[104] H. Shapley to P. W. Bridgman, Aug. 14, 1944, PWBP, HUG 4234.15.
[105] H. Shapley to P. W. Bridgman, Aug. 22, 1944, PWBP, HUG 4234.15.

Bridgman of Baker's letter telling that he would not care to associate himself with a symposium in which Russian scientists would take part.[106] Davies even suspected that Baker and the Society for Freedom in Science might be anti-Russian and pan-German. Bridgman denied her suspicion by explaining that one of the active members of the society Michael Polanyi was anti-Nazi,[107] but noticed that Shapley was going to twist things to his advantage, circulating the story that the *Free World* had declined Baker's article as he was so rabidly anti-Russian.[108]

In the end, *Science* published Bok's letter[109] in the September 8 issue, together with another article by Sydney Ross, which seemed to Bridgman to "neutralize"[110] Bok's. Ross's letter emphasized need for an organization for scientific freedom, showing that the British Society did not duplicate AASW.

7.3. Bridgman on Social Responsibility

7.3.1. The Deferment and Bridgman's Prospect for Intelligence

Toward the end of the war, Bridgman noticed another threat to science and again felt urged to publish his view of the social status of scientists: In late 1943, as D-Day came into sight, the Army manpower officers started to require the Government to tighten restrictions on occupational deferments.

Since September 1940, students of physics and electronics in the United States had usually been able to secure deferment as physicists-in-training, based on a statement of information from their

[106] B. Davies to P. W. Bridgman, Aug. 25, 1944, PWBP, HUG 4234.15.
[107] P. W. Bridgman to B. Davies, Sept. 13, 1944, PWBP, HUG 4234.15.
[108] P. W. Bridgman to J. Baker, Sept. 13, 1944, PWBP, HUG 4234.15.
[109] "Freedom in Science," *Science*, 100 (1944), pp. 217-219.

institutions and the directives issued by General Lewis B. Hershey, the director of Selective Service. Seniors or graduate students could also secure deferment through the intervention of the war research organizations. Research projects under the Office of Scientific Research and Development could accept students for employment six months before completion of their training and request their deferment when necessary. However, in 1942, new rulings made it impossible for some projects to request deferment more than two months in advance of the time when the person concerned was to begin work.[111] Furthermore, in early 1944, as the Army found it necessary to prepare more infantry divisions for D-Day in Normandy than it had expected, Congress and the Government took a series of actions against occupational deferments.[112]

In September 1944, Bridgman completed an essay "The Prospect for Intelligence"[113] and stated that the popular reaction to the draft was an example of people's intellectual inadequacy in meeting the crises caused by the war. In his observation, the majority felt that since no young man should be spared from sharing the hazards of combat duty, it was contemptible if a specially qualified young man was willing to render service more valuable to the country from some protected niche in a research laboratory. Admitting that the situation concerning occupational deferments was "simply too difficult for our minds to deal with,"[114] Bridgman pointed to the need for greater intellectual power to cope with these social problems. Since he regarded the development of

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110 P. W. Bridgman to J. Baker, Sept. 13, 1944, PWBP, HUG 4234.15.
111 James Phinney Baxter, 3rd, *Scientists against Time* (Boston: Little, Brown and Company, 1950), pp. 126-135.
112 Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (Cambridge, Mass. and London, England: Harvard University Press, 1987), pp. 321-322.
113 P. W. Bridgman, "The Prospect for Intelligence," *Yale Review*, 34 (1945), pp. 444-461; reprinted in *Reflection of a Physicist*, pp. 526-552.

modern science as an appropriate example of such intellectual enhancement, he ended up presenting his views of the scientific method and the prospect for intelligence in an essay begun by his remarks on the public attitude toward the deferment.

Bridgman did not hold that "there is a scientific method as such": "The scientific method, as far as it is a method, is nothing more than doing one's damnedest with one's mind, no holds barred."[115] To him, not the method but the subject matter seemed to distinguish science from other enterprises. Nevertheless, in order to draw lessons from the history of modern science, he first distinguished two epochs in it: "The first runs from Galileo and Newton to the first part of the present century," and "[t]he second epoch begins with this century, with the revolutions in scientific thinking involved in relativity theory and quantum mechanics."[116] Since the first epoch had run its course, Bridgman appreciated its significance only "with a certain degree of finality." Yet, he recognized that it had produced "a new trick of intellectual technique," namely, "the controlled experiment," which had established factual discoveries about the constitution of the world and had made nearly the whole domain of physical phenomena fall into scientists' hands.[117]

Bridgman characterized the second scientific epoch as an era of the discoveries of the astonishing facts in the microscopic domain and astronomy. These new facts had turned out to differ deeply from what scientists had conceived to be the possible order of nature and urged scientists to analyze the foundations of their thinking and revise their entire conceptual structure. Bridgman reiterated remarks similar to

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[114] *Ibid.*, p. 529.
[115] *Ibid.*, p. 535.
[116] *Ibid.*, p. 536.
[117] *Ibid.*, pp. 537-538.

the ones he had made in "The New Vision of Science" in 1929:

> The full impact of this new outlook will, I believe, ultimately be more devastating than was ever the impact of evolution. We may also anticipate that the impact will be more emancipating, because we shall know when to give up striving to do with our minds things which are intrinsically impossible.[118]

In describing what he regarded as the essentials of the scientific method, Bridgman was literally detailing what he had gone through in the formation and transformation of his operational view.

Yet, Bridgman was not as pessimistic as a decade before. He believed that scientists had come out of the second epoch with a new intellectual technique of analysis that possessed "great power and unexpectedly wide range of applicability." This technique taught scientists that man was isolated "in an oasis of phenomena which he never will be able to transcend because beyond its bounds the operations are impossible which are necessary to give meaning to his thought."[119] Bridgman anticipated that the new technique, when applied as the technique of verbal analysis, was applicable to all questions of meaning, including social ones, and would be able to eliminate "all human difficulties which arise from imperfect communication of meaning."[120]

Bridgman was not overoptimistic, either. Though he believed that the new technique of verbal analysis would be fruitful only in a democracy, he was not sure whether the public opinion in his country was "liberal enough to stand for, much less support, such a program of ruthless analysis."[121]

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[118] *Ibid.*, p. 540.
[119] *Ibid.*, p. 540.
[120] *Ibid.*, p. 543.
[121] *Ibid.*, p. 545.

> There are disquieting evidences that the line of future development of democracy in this country may be increasingly inimical to the unlimited development of intelligence. The majority appear not to enjoy using their minds or to be inclined to put themselves out in order that others may.[122]

Bridgman observed that the majority not only disliked using their minds but also felt that they had a right to force mental work on the minority, as the Kilgore bill for the mobilization and control of scientific activity had illustrated.[123] However, Bridgman estimated that the bill would defeat itself, because "no minority will long suffer the consciousness of being exploited as a class."

Bridgman contended that the intelligentsia "who like to use their minds better than anything else they can do" should direct the development of intelligence, since no one else was capable of it.[124] Nevertheless, the intelligentsia had not fully recognized this important task and its possibilities yet. As the public attitude toward occupational deferments showed, people in a democracy were often insensitive to "the very undemocratic distribution of talents by nature" and tended to require equal treatment for all on the ground that all were of equal value. Only the intelligentsia, who knew "how rare true ability is, and how important for progress,"[125] could urge society to give unusual ability "any special treatment necessary to induce it to produce capacity,"[126] but so far they had not been willing to push the matter. Though understanding that the intelligentsia found it distasteful "to urge [their] fellows to grant special service to [themselves], no matter how justifiable the grounds," Bridgman asserted that "here is no place

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122 *Ibid.*, pp. 545-546.
123 *Ibid.*, p. 546-547.
124 *Ibid.*, p. 548.
125 *Ibid.*, p. 549.

for false modesty." He required them to say bluntly: "We have special abilities which make us of special importance to the community, and we demand that we be given suitable opportunity to use our abilities and that we be rewarded according to what we produce."[127]

However, Bridgman only saw that the contemporary scientists had missed an opportunity to get the country to accept the privilege of the gifted: "Our scientific leaders who have been directing the war research of the country have not been able to withstand the pressure, exerted presumably by the military, to treat all young men between the ages of 18 and 26 on an equal footing, regardless of proved or potential unusual ability."[128] While intellectual defeatism and appeasement was widespread, intellectual morale, "without which all these others will be in vain," currently seemed to him to be low. Furthermore, Bridgman feared that the entire world would soon become of "one piece, with all parts so interlocked that independent action by the parts may become impossible, frozen in the pattern which happens to prevail at the moment of union."[129] Still, he admitted that since the outbreak of the war the entire situation had been favorable for the enhancement of intellectual morale, because of the widely diffused leaven of the scientific temper and a powerful stimulus provided by obvious necessity of unusual ability in science: "It will take effort to get started on the way out, but once started, progress will be accelerated." Bridgman therefore concluded the essay by a warning: "It is getting late and we must hurry."[130]

Toward the end of the war, the growing threat of the draft turned Bridgman's attention from the advocacy of scientific freedom to the

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126 *Ibid.*, p. 550.
127 *Ibid.*, p. 550.
128 *Ibid.*, pp. 550-551.
129 *Ibid.*, p. 551-552.
130 *Ibid.*, p. 552.

claim for scientists' privileges. Attempting to protect the social status of scientists by taking advantage of the escalating importance of scientists' wartime cooperation, Bridgman boldly criticized the shortsightedness of a line of philosophy of democracy that required equal treatment for all and maintained that from the long-range point of view the cherishment and encouragement of unusual ability would eventually become "important for everyone."[131]

Bridgman made a serious effort to publish this essay in a popular magazine. In September 1944, he sent the manuscript to the editor of *Harper's Magazine*, George Leighton, who had been instrumental in publishing his two earlier essays, but received only a conventional printed rejection slip, since Leighton was no longer at *Harper's*. Bridgman asked for a statement as to the specific reasons for the rejection.

> This is a matter of some little importance for me. I do not write this sort of thing easily and I spent much time at it. I am considering whether I ought not to abandon entirely the attempt to do this sort of thing and confine myself to my technical physics.[132]

Bridgman was not a type of person who could write popular articles easily. He ventured to write them only when he found anything worth publishing. Seeing the increasing pressure for the restriction of occupational deferments, he decided to do what he was not usually willing to do.

After another editor of *Harper's* promised to reconsider Bridgman's essay, but after reviewing it once, he rejected it again.

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[131] *Ibid.*, p. 549.
[132] P. W. Bridgman to George Leighton, Oct. 9, 1944, PWBP, HUG 4234.10.

> It strikes us that the merits of the general argument are obscured by their apparent dependence on observations which would strike many readers as doubtful. For example, you seem to have an unusually unhappy impression of the public attitude toward draft-deferred workers – an attitude which in our experience has been almost nonexistent.[133]

Not many seem to have shared Bridgman's observation of the public reaction to occupational deferments. Though Bridgman revised his manuscript thoroughly, *Harper's* did not accept it. The essay was published in the *Yale Review* the next year, when the draft crisis had already been over.

7.3.2. Scientists' Responsibility

During World War II, Bridgman's only concern was how to protect freedom and privileges of scientists. He found no problem in working voluntarily for the state's needs. By the early summer of 1943, he was devoting all of his time for wartime projects and remained so until the end of the war. He sent data of compressibility of uranium and plutonium to Los Alamos and probably understood at least vaguely the nature of weapons developed there from his communications with J. Robert Oppenheimer and Francis Birch. Younger scientists close to Bridgman could not but express their anxiety when they finished a test of an atomic bomb or when they learned of what their bombs caused in Hiroshima and Nagasaki. Kenneth Bainbridge, for example, said to Oppenheimer, "Now we are all sons of bitches," after having successfully completing the Trinity test, and Oppenheimer felt that it was the best thing anyone said then.[134] Meanwhile, after the war

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[133] John A. Kouwenhoven to P. W. Bridgman, Oct. 27, 1944, PWBP, HUG 4234.10.
[134] Kenneth T. Bainbridge, "A Foul and Awesome Display," *Bulletin of the Atomic Scientists*, 31:5 (May 1975), pp. 40-46, p. 46.

Bridgman only praised the efforts of scientists involved and hoped that they could get back to their own work soon.[135] In September 1946, when he had a chance to talk on "Physical Science and Human Values" at the Princeton Bicentennial Conference, he chose to discuss "New Vistas for Intelligence"[136] and delivered an lecture on almost the same subject as he had detailed two years before in "The Prospect for Intelligence," namely, how to apply the methods of science to the field of values, though he admitted that the invention of the atomic bomb had presented "problems which must be solved within the next few decades if the survival of civilization is to be more than a matter of good luck."[137]

In December 1946, the American Association for the Advancement of Science (AAAS) organized a joint symposium titled "How far can scientific method determine the ends for which scientific discoveries are used?" Bridgman, who had just been awarded the Nobel Prize and had been known for his protests against the wartime control of scientific activity, was invited to address his views on this topic.[138] He was aware of the younger generation's concern with the social effects of scientific discoveries, culminating in the atomic bomb, but did not approve any social philosophy that imposed a responsibility on the individual scientist. Pointing out that the applications of scientific discoveries were usually made by industrialists, not by scientists, Bridgman suggested that society could deal with the issues raised by scientific discoveries by other methods than by "forcing the scientist to do something uncongenial, something for which he is often not

[135] P. W. Bridgman to Francis Birch, August 30, 1945, PWBP, HUG 4234.10; P. W. Bridgman to Cyril S. Smith, Sept. 10, 1945, PWBP, HUG 4234.17.
[136] P. W. Bridgman, "New Vistas for Intelligence," in *Physical Science and Human Values* (Princeton University Press, 1947); *Reflection of a Physicist*, pp. 553-568.
[137] *Ibid.*, p. 553.
[138] P. W. Bridgman, "Scientists and Social Responsibility," *Scientific Monthly*, 65 (1947), pp. 148-154: *Reflection of a Physicist*, pp. 415-430.

fitted."[139] Revisions in the patent laws, for example, would be pertinent. Or, "if [society] had not wanted to construct an atomic bomb, it needed not have signed the check for the two billion dollars which alone made it possible."[140] To put the same matter more simply, "if society would only abolish war, 99 per cent of the need for the control of scientific discoveries would vanish."[141] And, to Bridgman, "it is obvious enough that the abolition of war is the business of everyone."[142] Bridgman could thus protect freedom of scientific activities: While society is responsible for the applications of scientific discoveries, there should be no restriction to scientists' activities.

Bridgman noticed that younger generation had different views on scientists' social responsibility.

> It is well known that the scientists who have shown the most articulate concern with the social implications of the atomic bomb are young. The philosophy that is coming into being betrays this. It is a youthful philosophy, enthusiastic, idealistic, and colored by eagerness for self-sacrifice. It glories in accepting the responsibility of science to society and refuses to countenance any concern of the scientist with his own interests, even if it can be demonstrated that these interests are also the interests of everyone.[143]

However, to him, their social philosophy seemed to be "short-range," "inadequate," and "unmindful of long-range considerations and blind to the existence of other scales of values than those of the philosophers themselves."[144] Instead of self-sacrifice, Bridgman assigned scientists "a position of high strategic importance" and an educative task, a task

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[139] *Ibid.*, p. 423.
[140] *Ibid.*
[141] *Ibid.*, p. 424.
[142] *Ibid.*
[143] *Ibid.*, p. 425.
[144] *Ibid.*, pp. 425-426.

> to get the average man to feel that the life of the intellect not only is a good life for those who actively lead it, but that it is also good for society as a whole that the intellectual life should be made possible for those capable of it, and that it should be prized and rewarded by the entire community.[145]

Bridgman never doubted the social legitimacy of scientific activity. In his views, society should recognize intellectual achievement as "one of the chief glories of man"[146] and should esteem the fear of its own intellect "an ignoble thing."[147] Bridgman assigned scientists a position to lead society to this goal, dreaming that "[i]n a society so constituted [...] the problems created by scientific discoveries will pretty much solve themselves."[148]

To Bridgman, younger physicists concerned too deeply with scientists' responsibility seemed even immature. On Oppenheimer's statement in 1948 that science now knew a profound guilt, Bridgman was reported to have commented, "If anybody should feel guilty, it's God. He put the fact there."[149] He understood Oppenheimer speaking of a sense of sin for himself, but resented his speaking for the rest of physicists:

> If a man does his damnedest after due consideration, as did all the physicists who worked on the atomic bomb, and then still feels a sense of sin, it simply means that he hasn't grown up yet and is pathologically unwilling to accept the contruction [*sic*] of the world about him.[150]

While fiercely fighting to protect scientists' right as citizens of free states,

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145 *Ibid.*, p. 428.
146 *Ibid.*, p. 430.
147 *Ibid.*, p. 429.
148 *Ibid.*, p. 430.
149 Paul Sabine to P. W. Bridgman, undated, PWBP, HUG 4234.10.

Bridgman knew that on some occasions they should only accept the inevitable, even though "damnedest," results of what they did after due consideration, as other citizens would have no choice but to do the same in many similar situations. The bombing of Hiroshima and Nagasaki did not seem to lead him to recognize the social responsibility of scientists different from that of others who do not have access to power and status that only science creates.

Probably Bridgman was too old to be sensitive to new questions that World War II presented to scientists. During the war Bridgman ventured to take the only political action in his life in order to maintain a somewhat outdated ideal, freedom in science, but failed to grasp the other aspects of the changing relation between scientists and their society. After he received the Nobel Prize in Physics in December 1946 and became known as a Nobel Laureate who had published his own philosophy of science and had bluntly criticized the mobilization of scientists during the war, Bridgman, though seldom involved in any political activity as he had been during the war, received more invitations than before to address his view of the relation between science and society. Aware of the growing tendency toward national planning of scientific research, Bridgman welcomed these invitations and contended the same belief in the supremacy of science over any other social activity as he had done before and during World War II.

Bridgman did not reveal how he had formed his view of the relation between science and society, nor did he mention who he expected to support it. One can only find that some contemporaries such as Michael Polanyi, who opposed to the movement to describe science only in terms of social and economic influences, shared a similar view.

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[150] P. W. Bridgman to P. Sabine, Nov. 16, 1948, PWBP, HUG 4234.10.

Their effort for scientific freedom was not very popular among scientists in Europe and America during World War II, and remained so after that, partly because of growing international tensions in the postwar years that created new financial and political opportunities for scientists.

Still, Bridgman never felt it necessary to scrutinize his belief in the social legitimacy of science. Convinced of the special social status of science and scientists, Bridgman took no interest in developing his operational perspective of science for the purpose of explicating the social function of science. While he kept inquiring what operation each physical concept corresponded to, he never wondered how science and scientists operated in society. Operationalism thus remained to be a way of interpreting the meanings of physical concepts that had little implication in the social aspects of science.

Chapter 8. Bridgman in the Postwar Years

During the war, Bridgman started to improve the method of measuring compressibility up to 100,000 kg/cm^2 and found a new research subject, plastic flow under pressure, which for him had "real scientific interest, in spite of its utilitarian smell"[1] and would later result in a book *Studies in Large Plastic Flow and Fracture.*[2] Having nearly finished all of his war work by the beginning of August 1945, Bridgman was hoping to be back to "purely useless things" the next winter. Yet, he could not expect much time left for his favorite experiment. Like his older colleagues, he planned to retire voluntarily at the age of 65, namely, in 1947.[3]

However, since Bridgman received the Nobel Prize in Physics for 1946, his plan for the rest of his life had changed considerably. Bridgman was appointed Higgins University Professor in 1950 and continued his experimental work even after his appointment as Professor Emeritus in 1954.[4] Furthermore, as he gradually became known outside scientific community as a Nobel Laureate in Physics who had been publishing in popular magazines his own philosophy of science and analysis of social issues, he started to enjoy chances to address his views to various audiences.

Bridgman's straightforwardness underwent no major change for the postwar period. He did not hesitate to speak out when he saw it necessary. In 1948, for instance, when the House Committee on Un-American Activities attacked E. U. Condon for his alleged disloyalty, Bridgman, E. M. Morgan, Professor of Law at Harvard, and J. C. Slater were appointed by the Council of the American Academy of Arts and

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[1] P. W. Bridgman to M. Born, Aug. 4, 1945, PWBP, HUG 4234.10.
[2] P. W. Bridgman, *Studies in Large Plastic Flow and Fracture, with Special Emphasis on the Effects of Hydrostatic Pressure* (New York: MacGraw-Hill Book Co., Inc., 1952).
[3] P. W. Bridgman, "Memorandum to Professor Kemble," Dec. 10, 1943, DPCC, UA V, 691.10.
[4] P. W. Bridgman to M. Born, Nov. 4, 1954, PWBP, HUG 4234.10.

Sciences to report the details of the case. They proposed the Academy to publish a statement that the Fellows of the Academy condemned the committee's procedure in publishing charges against Condon on inadequate evidence and without giving him an adequate chance to present his case.[5] The next year, Bridgman urged the National Academy of Sciences to act independently of the Federal Government's policy as it was "the highest representative of science"[6] in the United States. On another occasion, he wrote to the President of the National Academy, "It seems to me that there are certain traditions in our democratic inheritance which are more precious than the exigencies of the moment created by the atomic bomb emergency."[7] Moreover, in 1953, when Nathan Pusey was appointed President of Harvard, Bridgman publicly deplored that anti-intellectualism of Eisenhower and Nixon caused a grave change of emphasis at his university.[8] Bridgman maintained the same ideal of freedom of scientific activity and intellectual integrity as he had emphasized during World War II.

In the postwar years, however, Bridgman did not the feel need to fight for scientific freedom as militantly as during World War II. Although he remained to be American representative of the British Society for Freedom in Science, he thought by the beginning of 1950s that the Society had accomplished its most important mission, namely "to emphasize the need for freedom in science and the impossibility of such freedom in a totalitarian regime such as Russia."[9] Furthermore, some scientists including Bridgman founded a journal *The Bulletin of the*

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[5] P. W. Bridgman, E. M. Morgan, and J. C. Slater to the Fellows of the American Academy of Arts and Sciences, April 5, 1948, PWBP, HUG 4234.10.
[6] Jessica Wang, *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War* (Chapel Hill and London: The University of North Carolina Press, 1999), p. 194.
[7] Jessica Wang, *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War*, p. 246.
[8] B. F. Skinner, *A Matter of Consequences* (New York: New York University Press, 1984), p. 126.
[9] P. W. Bridgman to John Baker, Nov. 3, 1952, PWBP, HUG 4234.15.

Atomic Scientists, which played an important role in calling the attention of the American scientists to the same issues that the British Society had been publicizing.[10]

Nor did Bridgman feel it necessary to spread his operational approach more widely. After the war, while psychologists gradually lost their interest in Bridgman's philosophy of science, various philosophers, influenced by the rise of logical positivism, developed their analysis of the operational approach beyond its originator's reach. On December 27 – 30, 1953, sponsored by the American Academy of Arts and Sciences and the National Science Foundation, the Institute for the Unity of Science organized a conference titled "The Validation of Scientific Theories" and devoted one of the seminars to the "Present State of Operationalism." The speakers besides Bridgman were Henry Margenau (Yale), Gustav Bergmann (Iowa), Carl Hempel (Yale), R. B. Lindsay (Brown), R. J. Seeger (the National Science Foundation), A. Grünbaum (Lehigh), and S. S. Stevens (Harvard). All of them, including Bridgman, recognized the importance of operation in clarifying the meaning of scientific concepts, but admitted that operationalism was not a systematic and consistent philosophy.[11] Bridgman, however, was surprised to see the other speakers' general attitudes toward operational analysis:

> As I listened to the papers I felt that I have only a historical connection with this thing called "operationalism." In short, I feel that I have created a Frankenstein, which has certainly got away from me. I abhor the word operationalism or operationism, which seems to imply a dogma, or at least a thesis of some kind. The thing I have envisaged is too simple to be dignified by so pretentious a name.[12]

Bridgman found some philosophers of science attempting to formalize

[10] P. W. Bridgman to Alfred Plaut, March 16, 1953, PWBP, HUG 4234.15.

[11] Philipp G. Frank, ed., *The Validation of Scientific Theories* (New York: Collier Books, 1961), pp. 43-92.

[12] P. W. Bridgman, "The Present State of Operationalism," in, Philipp G. Frank, ed., *The Validation of Scientific Theories* (New York: Collier Books, 1961), pp. 75-80, pp. 75-76.

scientific theorizing and expected operationalism to present a clue to the understanding of the relation between experimental results and scientific theory. Yet, he did not share this sort of interest, as his intention was much more modest: He only wanted to find something that could alleviate his intellectual distress caused by dimensional analysis, relativity theory, and later the uncertainly principle. After finishing the struggle to examine the details of quantum mechanics, Bridgman had never been enthusiastic over further development of operational analysis as a systematic science theory.

Among the participants in the symposium, Margenau most succinctly described the defects of operationalism.[13] First, he declared, since Bridgman failed to present a clear definition of the concept of operation, operationalism could become either trivial (if it admitted mental and "paper-and-pencil" operations) or too restrictive (when "operations" meant only laboratory procedures.) Second, he went on, operationalism could not define substantive concepts: it could, for example, define such physical quantities as the mass, the charge, and the spin of an electron, but not the electron itself. Perhaps Margenau should have added that Bridgman never seemed to have expected that scientists could do without these substantive concepts. At any rate, philosophers of science of the 1950s gave a clear expression to the vulnerabilities of operationalism that psychologists of the 1930s had found in their methodological debates.

Bridgman found it more attractive to apply operational reasoning to social philosophy. At Harvard, taking the advantage of his appointment as a University Professor, Bridgman ventured to ask his sociologist colleague Talcott Parsons at the Department of Social Relations to allow him to deliver a graduate course in which he would "make an experiment

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[13] Henry Margenau, "Interpretations and Misinterpretations of Operationalism," in, Philipp G. Frank, ed., *The Validation of Scientific Theories* (New York: Collier Books, 1961), pp. 45-46.

in the application of the operational method to certain social questions."[14] Parsons accepted Bridgman's offer. Thus Bridgman organized a seminar on "The Logic of Agreement," the title suggested by James Conant,[15] for one year in 1952-53. Bridgman and three other participants including the young Ph. D. candidate Henry Kissinger spent one year in exploring an attempt to apply the operational method to the solution of social problems, but, as Kissinger later recalled, did not get "very far."[16] Kissinger's impression was that "the task [Bridgman] set himself was so novel for him that his contribution [...] may not have been of lasting significance." Furthermore, Kissinger found Bridgman's works on the social sciences he read in the course of the year "not of ultimate stature."

After his retirement in June 1954, Bridgman became able to spend more time on writing than before and started to enjoy mostly favorable responses. To his article on the future of science and humanities published in 1958,[17] Dennis Gabor at the University of London sent a flattering thanking for "expressing so admirably [his] innermost feelings."[18] The letter gave Bridgman "a lift which [he did] not get very often." As always, Bridgman had been feeling like "a prophet in the wilderness": "[I]t all seems so very obvious to me and so incomprensible [*sic*] that so few other people see the same thing."[19]

In 1959, Bridgman published his social philosophy in a book *The Way Things Are.*[20] Though some reviewers criticized it "long, abstract and difficult" or failed to get its significant point, Bridgman received several encouraging reactions to the book and found favorable reviews by

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[14] P. W. Bridgman to Talcott Parsons, Feb. 11, 1950, PWBP, HUG 4234.10.
[15] P. W. Bridgman, *The Way Things Are* (Cambridge, Mass.: Harvard University Press, 1959), p. 245.
[16] Henry Kissinger to E. C. Kemble, Dec. 6, 1961, ECKP, HUG (FP) 72.10.
[17] P. W. Bridgman, "Quo Vadis," *Deadalus,* 87 (1958), pp. 85-93.
[18] Dennis Gabor to P. W. Bridgman, Aug. 11, 1960, PWBP, HUG 4234.11.
[19] P. W. Bridgman to Dennis Gabor, undated, PWBP, HUG 4234.11.
[20] P. W. Bridgman, *The Way Things Are* (Cambridge, Mass.: Harvard University Press, 1959).

Arthur Compton and Linus Pauling.[21] Moreover, *The Way Things Are* turned out to delight its author in an unexpected way: The American Library Association selected it as one of the forty nine "Notable Books of 1959."[22] However, it was mostly natural scientists close to Bridgman who found the book valuable; philosophers and social scientists practically ignored it, as far as Bridgman could judge.[23] Before its publication, the publisher's referee had already pointed out that Bridgman's social philosophy was "highly idiosyncratic, one that might have conceivably been written by a gifted mind a century ago."[24]

Bridgman sent a copy of *The Way Things Are* to B. F. Skinner with a note: "Here it is. Now do your damnedest!" One chapter of the book was extended criticism of behaviorism.[25] Since the symposium in 1945, the discussion between them had continued without much change in each one's position. Yet, busy with other things, Skinner did nothing about the book and missed the last chance to argue with Bridgman.[26] Soon after the publication of *The Way Things Are,* Skinner observed that Bridgman began to fail. In their last public discussion, Bridgman "forgot words, lost the thread of his remarks, and was deeply distressed."[27] "He has lived too long," Skinner put in a note.

Though to Skinner Bridgman was "one man [he] *did* argue with," Skinner later recalled that he could never have convinced Bridgman, since, according to Skinner, it was not a matter of conviction. Skinner regarded behaviorism as a working hypothesis of the nature of human

[21] P. W. Bridgman to Murray Ley, Sept. 21, 1959; Swan Harding to P. W. Bridgman, May 3, 1959; Raymond J. Seeger to P. W. Bridgman, Oct. 14, 1959; P. W. Bridgman to Linus Pauling, Dec. 1, 1959; J. T. Edsall to P. W. Bridgman, Dec. 3, 1959, PWBP, HUG 4234.15.
[22] Thomas J. Wilson to P. W. Bridgman, Feb. 16, 1960, PWBP, HUG 4234.15.
[23] P. W. Bridgman to Murray Ley, Sept. 3, 1959, PWBP, HUG 4234.15.
[24] Thomas J. Wilson to P. W. Bridgman, July 15, 1958, PWBP, HUG 4234.10.
[25] Bridgman, *The Way Things Are*, pp. 200-248.
[26] B. F. Skinner, "B. F. Skinner," in Edwin G. Boring and Gardner Lindzey, eds., *A History of Psychology in Autobiography*, Vol. V (New York: Appleton-Century-Crofts, 1967), pp. 387-413, p. 409.
[27] Skinner, *A Matter of Consequences*, p. 280.

behavior formulated for an effective experimental approach to the subject of psychological research. He had no doubt of the triumph of behaviorism as research program, but this did not mean that he believed that it would eventually be proved right.

The intellectual atmosphere at Harvard that surrounded Bridgman's discussion with psychologists and philosophers stimulated the Harvard project for the history of science. After the war, Bridgman's interest in philosophy was further developed by Philipp Frank, a refugee philosopher-physicist appointed as a lecturer at the Harvard Physics Department. His multiyear appointment was realized by Bridgman, Kemble, and Harlow Shapley in 1940.[28] Frank, as the President of the Institute for the Unity of Science, worked energetically to propagate philosophy of science, and lively discussion was frequently held at the Institute, which was attended by such regular members as Bridgman, Richard von Mises, W. V. Quine, E. G. Boring, and S. S. Stevens, as well as such visitors as Bertrand Russell and R. Carnap. H. Feigl observed that "there was a sort of revival of the Vienna Circle."[29] President James B. Conant also sympathized with this group.

Among the Harvard Physicists, E. C. Kemble took the lead in the project for the course in history of science. Kemble had once led theoretical research at Harvard, but had failed to plunge into quantum-mechanical research in molecular physics in the late 1920s. After the war, he could no longer keep up with the new development in theoretical research.[30] Experimentalists like Bridgman whose field was less affected by the shifts in the theoretical scheme of physics could remain active in their research until they decided to retire. Theoretical

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[28] Gerald Holton, "Ernst Mach and the Fortunes of Positivism in America," *Isis*, 83 (1992), pp. 27-60.

[29] Herbert Feigl, "The Wiener Kreis in America," in Donald Fleming and Bernard Bailyn eds., *The Intellectual Migration* (Cambridge, Mass.: Harvard University Press, 1969), pp. 660-661.

[30] Alexi Assmus, "Edwin C. Kemble, January 28, 1889-March 12, 1984," *National Academy of Sciences of the United States of America, Biographical Memoirs*, 76 (1999), pp. 179-197.

physicists, on the other hand, could not easily catch up with the drastic changes in the mode of physical research, once they dropped out. After serving as the Chairman of the Physics Department during the war, Kemble shifted his interest to general education and history and philosophy of science.[31] President Conant, who found the history of science useful in building "a bridge between the humanities and the technicalities of science"[32] after his experience in the atomic bomb project, started the general education program for teaching the history of science at Harvard. To materialize Conant's idea, Kemble set up a lunchtime group at the Physics Department, which included the future historians of science I. B. Cohen, Gerald Holton, Thomas S. Kuhn, Philippe Le Corbeiller, and Leonard K. Nash.[33]

The program in history of science at Harvard was thus originated, with help from Kemble and young physicists and intellectual stimulus of logical positivism. Holton, who earned his Ph. D. under Bridgman's supervision and then turned to history of science, included an introduction of Bridgman's operational point of view in his textbook of physics written in the early 1950s.[34] Bridgman himself did not do much for the program in history of science at Harvard, but the intellectual atmosphere at Harvard under Conant's presidency, characterized by philosophers' logical positivism, psychologists' behaviorism, and Bridgman's operationism, was at least indirectly responsible for the establishment of the department of history of science at Harvard.[35]

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[31] E. C. Kemble, "Reality, Measurement, and the State of the System in Quantum Mechanics," *Philosophy of Science*, 18 (1951), pp. 273-299; E. C. Kemble, *Physical Science, Its Structure and Development* (Cambridge, Mass.: MIT Press, 1966).
[32] James Hershberg, *James B. Conant: Harvard to Hiroshima and the Making of the Nuclear Age* (New York: Alfred Knoph, 1993), p. 499.
[33] Alexi Assmus, "Edwin C. Kemble, January 28, 1889-March 12, 1984," *National Academy of Sciences of the United States of America, Biographical Memoirs*, 76 (1999), p. 191.
[34] S. G. Brush, "Introduction to the Second Edition," in G. Holton and S. G. Brush, *Introduction to Concepts and Theories in Physical Science*, 2nd ed. (Reading, Mass.: Addison-Wesley Publishing Co., 1973), pp. vii-ix.
[35] Jensine Andresen, "Crisis and Kuhn," *Isis*, 90 (1999), pp. S43-S67; Gerald Holton,

Bridgman's death was tragic. In July 1961, he found that he had an intractable cancer of the bones of the pelvic region which would develop rapidly, cause increasing pain and loss of muscle control, and eventually prove fatal in a few months. On August 20, Bridgman was found dead in the pumphouse behind his summer house in Randolph, New Hampshire. He had shot himself in the head with a shotgun placed in his mouth. The barrel of the gun had carefully been sawn off. Bridgman's last note left in his pocket read, "It isn't decent for Society to make a man do this thing himself. Probably this is the last day I will be able to do it myself."[36] At the last moment of his life, Bridgman had to realize that society was not constituted in the way he regarded as rational.

However, perhaps it is not appropriate to conclude this chapter by Bridgman's dramatic last note. Although Bridgman quit his experimental work in the spring of 1956, he continued to write on various issues in high-pressure physics. Even in the summer of 1961, when he learned of his inoperable cancer, besides completing a monograph *The Sophisticate's Primer of Relativity* and a book review for *Science*, he prepared an introduction and commentaries for his collected experimental papers. The editors of the latter noticed that he had apparently worked on a draft of the introduction and commentaries the day before his death.[37] In his last technical article, which was published posthumously in 1963 as the first paper for the book titled *Solids under*

"Some Lessons from Living in the History of Science," Isis, 90 (1999), pp. S95-S116; Joy Harvey, "History of Science, History of Science, and Natural Sciences: Undergraduate Teaching of the History of Science at Harvard, 1938-1970," pp. S270-S294; Thomas S. Kuhn, *The Road since Structure* (Chicago and London: The University of Chicago Press, 2000), pp. 253-323.

[36] Edwin C. Kemble and Francis Birch, "Percy Williams Bridgman, April 21, 1882-August 20, 1961," *National Academy of Sciences of the United States of America, Biographical Memoirs*, 41 (1970), pp. 23-67, p. 48.

[37] Harvey Brooks, Francis Birch, Gerald Holton, and William Paul, "Preface by the Editorial Committee," in P. W. Bridgman, *Collected Experimental Papers*, 7 vols. (Cambridge, Mass.: Harvard University Press, 1964), vol. I, pp. xxi-xxiii, p. xxi.

Pressure,[38] Bridgman reviewed what he had done in high-pressure physics and detailed what he would have liked to pursue further. For example, the search for new unsuspected forms of matter continuously appeared attractive to him: he wrote, "[I]f I were again active in reaching new high pressure, I could not resist the temptation of subjecting plausible substances to the action of hitherto unreached pressures to see whether some permanent change had been produced."[39] Meanwhile, he did not miss a new tendency in this field and warned: "Whatever the ultimately successful method, it would seem that we must reconcile ourselves to the use of increasingly larger and more complex apparatus, with the increasing expense thereby implied, with perhaps, presently, instruments of the size [of] cyclotrons, and all the unwelcome features of government support."[40] Until his last moment, Bridgman had remained fond of the comfortable style and size of high-pressure research and had been concerned with its future more than anything.

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[38] William Paul and Douglas Warschauer, eds., *Solids under Pressure* (New York: MacGraw-Hill, 1963).
[39] P. W. Bridgman, "General Outlook on the Field of High-Pressure Research," in William Paul *et al.*, *Solids under Pressure*, pp. 1-13, p. 8.
[40] P. W. Bridgman, "General Outlook on the Field of High-Pressure Research," p. 6.

Conclusion

In the mid-1910s, when Bridgman started to reflect on the methodological aspect of physics, he had two objectives in his mind: to straighten out the confusion in the meanings of concepts in electromagnetism and relativity theory, and to assure the significance of experimental research in physics that some enthusiastic advocates of dimensional analysis began to underestimate. His scrutiny of the foundations of dimensional analysis successfully showed that the use of this theoretical tool presupposed knowledge of experiments and physical measurements that had been accumulated through "the experiences of all the ages." Convinced that he could clarify any complication by examining its experimental situation, Bridgman went on to analyze the general theory of relativity, which he eventually found to be a theoretical speculation. Thus, as I have clarified, operational analysis at first emerged as an experimentalist's way of interpreting and evaluating theoretical artifacts.

However, while Bridgman was comparing the special and general theories of relativity, a more ambitious goal came into his sight. The success of the special theory of relativity appeared to him to owe much to the operational definitions of physical concepts, such as simultaneity. Through his education and his activity for establishing theoretical research at Harvard, Bridgman had clearly recognized that he lived in the age of theoretical reform. The advent of relativity theory induced a revolution in the understanding of physical reality, and the recent development of quantum theory was about to cause another one. Bridgman expected that he could present a program for further reform by extrapolating his methodological discovery from phenomena in the realm of high velocities (special relativity) to those in the microscopic realm (quantum theory). Moreover, his program for reform in physical theory would assign an essential role to experimentalists. When Bridgman published *The Logic of Modern Physics* in 1927, he expected it to be read as a new guideline for theorizing in physics.

On the basis of Bridgman's program for reform lied several implicit presuppositions that Bridgman did not sufficiently detail in the *Logic*. One of them I have called the absoluteness of operation, which means that the same set of operations always lead to the same result if carried out by the same rule. This presupposition guarantees the one to one correspondence between concepts and operations.

Another presupposition of Bridgman's reasoning was connected with his understanding of the character of physics as knowledge of nature. When he formulated his operational stance, he believed that nature was intelligible and controllable in the same manner that well chosen operations were always realizable and repeatable. For him, the operational reasoning was a method to construct knowledge of nature so faithful that one could regard it as identical with nature. He believed that knowledge of nature would eventually conform to nature itself if operations could furnish all physical concepts with their repeatable, realizable definitions.

Furthermore, in the *Logic*, Bridgman sometimes mentioned physical reality as the object of physical study. Though he eventually ceased to refer to this concept before clarifying its meaning, its most important connotation for him was uniqueness. In the *Logic*, he believed that there should be one unique, or real, physical theory that faithfully described this unique physical reality.

As philosophers found in the 1950s, Bridgman's operational standpoint was too vague as a systematic philosophy of physics. However, decades before philosophers' criticism, Bridgman had to face a much tougher challenge of contemporary physical theory: Heisenberg's uncertainty principle devastated Bridgman's belief in the absoluteness of operation. Moreover, Bridgman found the structure of quantum mechanics present some features that made him abandon his belief in the uniqueness of physical reality. Bridgman first recognized that operations in the microscopic realm could not always lead to the same results, and then observed that current physical theory depending heavily on mathematics could no longer correspond to physical reality uniquely. Though no biographical account of Bridgman has mentioned it, his correspondence and essays written during his struggle with the uncertainty principle show emotional turbulence that was almost exceptional in his calm and steady scientific life. The turbulence culminates in his *Harper's* essay "The New Vision of Science," published in 1929.

The operational method gradually turned back or evolved into a tool for interpreting scientific concepts. The operational analysis was still valid as a method for scrutinizing physical theory, since even after the advent of quantum mechanics one could still regard operations as something intermediating what is described and what describes. While reformulating the operational method, Bridgman examined the tools and concepts adopted in quantum mechanics from this modified operational point of view and found that the absoluteness was not the nature of operations, but the criterion for operations adopted to characterize the realm of nature under consideration. In *The Nature of Thermodynamics*, he maintained that each physical theory had its own universe of operations whose character determined the nature of physical theory. In this new operational scheme, by preparing repeatable and controllable operations, one can construct physical theory that enables him or her to control physical phenomena.

Bridgman also understood that though quantum mechanics revealed certain uncontrollability of nature, this did not deny that some part of nature could be made to be controllable.

In the formation and evolution of Bridgman's operational view of science, Einstein's relativity and Heisenberg's uncertainty were of crucial importance. It is notable that Bridgman's responses to these two important notions in physics shared one characteristic: Bridgman overreacted or reacted improperly. Einstein bluntly rejected the conclusions that Bridgman drew from the special theory of relativity. Bridgman himself noticed in his last days that Einstein's definition of simultaneity, which he regarded as an ideal model of operational definition, was in fact operationally unstable. Furthermore, Bridgman may have found out that his peculiar interpretation of special relativity, which had led him to discover operational analysis, did not quite fit to Einstein's original intention. A few years before this, Bridgman had to face a similar situation concerning the uncertainty principle. In 1959, reviewing Heisenberg's philosophical writings in his *Physics and Philosophy,* Bridgman was astonished to find Heisenberg accept the conventional philosophical attitude and use the word "reality" [1] monotonously. Heisenberg's philosophical attitude did not seem to Bridgman to accommodate properly what he believed to be "the truly revolutionary implications of quantum theory." The same year, writing about the possible change he would like to make on rewriting the *Logic,* Bridgman admitted that "the most radical changes would be with respect to quantum phenomena, since the book was written coincidentally with the appearance of Schrödinger's wave equation," though the changes would not be "as great as [he] might have feared."[2]

[1] Bridgman, review of *Physics and Philosophy: The Revolution in Modern Science* by Werner Heisenberg, *Perspectives in Biology and Medicine*, 2 (1959), pp. 246-248.
[2] P. W. Bridgman, "P. W. Bridgman's 'The Logic of Modern Physics' after Thirty Years,"

Bridgman's younger colleagues did not share with him as much as Heisenberg did. While Bridgman attempted to examine the operational soundness of concepts adopted in physical theory, his younger physicists only required physical theory to explain and predict the results of experiments accurately. Considering physical theory as a black box that somehow allowed them to calculate physical quantities they asked for, they did not care about its mechanism or structure unnecessarily. They welcomed quantum mechanics since it functioned well to help them calculate physical quantities in the microscopic realm; Bridgman, however, could not easily accept many of its fundamental but startling concepts, such as an electron without its identity.

Bridgman did not accept quantum mechanics since he could not simply believe that this physical theory represented exact knowledge of reality, while young quantum physicists, who only required physical theory to be practical and useful, favored it. In his scrutiny of physical theory, Bridgman remained concerned mainly with its rigor and failed to notice other physicists' interest in its function. Though he saw quantum physicists accept quantum mechanics according to their functional standard, Bridgman did not venture to integrate this observation into his philosophical reflection on science.

However, young quantum physicists invoked Bridgman's operational methodology in justifying their acceptance of quantum mechanics. Furthermore, many of them justified their indifference to philosophical problems by quoting Bridgman's statement about the operational criterion for meaning. They paid little attention to such concepts as physical reality, and even when they did, they did not consider them as physicists' concern. For them, physical theory was a conventional tool to describe experimental results as simply and

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Daedalus, 88 (1959), p. 519.

conveniently as possible, so that new experiments could be designed and their results could be calculated. Young quantum physicists who favored the *Logic* as a guarantee for such attitudes were only dismayed by Bridgman's dramatic presentation of the uncertainty principle. Then they simply became indifferent to his effort to scrutinize the operational soundness of quantum-mechanical concepts. I contend that what can safely be pointed out about Bridgman's "influence" upon other physicists is some resonance between their statements: The concepts and phrases Bridgman coined for his operational methodology were interpreted in the context he had not originally aimed at.

Bridgman's advocacy of private science fitted well into such situation. After turning into a tool for interpretation, the operational method allowed one to comprehend scientific concepts in his or her personal context. Though the question of how one can guarantee the correctness of each interpretation still remains, tools for interpretation do not always need to be universally accepted. By adopting his own operational criterion for the philosophical implications of the uncertainty principles, Bridgman reached conclusions that startled many of his contemporaries. Meanwhile, his younger colleagues interpreted philosophical problems in physics according to the context they were facing as active researchers.

Even physicists close to Bridgman never expected operationalism to lead theoretical reform in physics. When they mentioned the *Logic* as their philosophical guide, they invoked it only as a standard for interpretation. Striving to acquire expertise in theoretical physics, American physicists of the late 1920s needed a guideline that would help them assimilate novel concepts, but not a program for reform.

On the other hand, psychologists in the 1930s found the *Logic* to be a reliable reference for constructing scientific concepts. While

Bridgman had by then reformulated the operational method into a hermeneutics, psychologists appreciated the *Logic* as a program for reform. Conscious of the theoretical reform in physics, they often referred to relativity theory and quantum mechanics and dreamed of a similar revolution in their field. They emphasized the importance of public operations for defining psychological concepts and blamed Bridgman for his insistence on private science. After a decade's methodological controversy, however, psychologists eventually found the operational approach unproductive.

The operational approach never succeeded as a program for reform. It is doomed to function merely as a framework for interpretation. Or, probably there exists no such thing as a general program for reform in science.

Furthermore, the crucial discussions that led Bridgman to form and transform his views of physics (Einstein's definition of simultaneity and Heisenberg's analysis of experimental uncertainty) were both based on thought experiments that no experimentalists had ever actually carried out. Bridgman's intellectual struggles show that it is theoretical speculation, not mere experimental facts, that eventually appeals to scientists' intellects.

Even as a framework for interpretation, the operational approach could have presented a wider range of possibility than it actually did. Historians and philosophers of science may naturally wonder why Bridgman did not broaden his perspective by exploring the implications of operationalism in the relation between science and technology. Operations play an essential role in the formation of physical theory, but probably not in the way Bridgman understood, as psychologists and philosophers discussed. Yet, when one examines what science does, not what it says, Bridgman's operational perspectives appears to be more promising. For example, the operational aspect of science stands out most clearly when science is put to work for industrial and military application. Bridgman, however, never considered this possibility of operationalism. In other words, he never attempted an operational analysis of science. Regarding science as knowledge of reality pursued for its own sake, he paid little attention to its practical aspect. Bridgman's experience in wartime projects did not change his recognition of the relation between science and society that he manifested, for example, in his wartime statements. He several times insisted not only that science existed for its own sake, but also that society existed for the sake of science. His activities for freedom in science during World War II, which has not been known among historians of science, reveal his firm belief in the value of science as an intellectual enterprise. Though concerned with technological application of his experimental research, he never attempted to analyze the nature of scientific knowledge with regard to its social function. Bridgman's unwillingness to analyze scientific knowledge as a social product formed the fatal limitations of his philosophical scope.

In the postwar years, Bridgman's methodology, even as a guideline for interpretation, ceased to attract as many physicists and psychologists as it had done the 1930s. In the 1950s, operationalism gradually became obsolete in the crossfire of the new generation of philosophers of science. Seeing in this light, some may want to dismiss Bridgman's long struggle with the challenges of contemporary physical theories as an episode of an experimentalist who awkwardly tried to adapt himself to drastic changes in physics but failed. Bridgman's peculiar understanding of operation may seem to be so absurd that no one but Bridgman would support. However, in his laboratory, Bridgman could expect his high-pressure experiment to be repeatable, as we expect most of our daily operations to be repeatable and their results to be predictable. One of the most significant duties of experimentalists like Bridgman is to establish their measurements as a set of repeatable operations. An important part of the credibility and universality of science rests upon their effort in this direction. Physics is meaningful only within a certain realm of operations, outside which there is in principle no guarantee for its validity. Physical theory is, whatever else it may be, knowledge of controllable operations. Though seeming strange at first sight, Bridgman's presupposition about the nature of operations, that operations should always bring the same result if carried out according to the same procedure, is in fact a criterion we adopt when we standardize experimental procedures. Bridgman's bewilderment at the uncertainty principle tells us that, in constructing the philosophy of experiment, one cannot avoid facing the question of what repeatability and controllability can still mean after the lessons of the uncertainty principle and quantum mechanics. Bridgman strove to answer this question by constructing the philosophy of physics that represented an experimentalist's reality threatened by formidable challenges of 20th-century physics.

Appendices

Table 1-1-1. The Courses Bridgman Took as an Undergraduate Student, 1900-1904.

SUBJECT	NUMBER OF FULL COURSES
English	1
German	2
French	1
Economics	1
Philosophy	1
Mathematics	9
Physics	6
Chemistry	2
TOTAL	23

Source: Kennedy to Kemble, July 26, 1962, ECKP, HUG (FP) 72.10.

Table 1-1-2. The Courses Givèn at the Mathematics Department which Bridgman Took as an Undergraduate Student, 1900-1904.

YEAR	SUBJECT-MATTER	INSTRUCTOR(S)	NUMBER OF FULL COURSES
00-01	Algebra	J. L. Coolidge	0.5
00-01	Solid Geometry	Bouton J. L. Coolidge	0.5
00-01	Trigonometry and Plane Analytic Geometry	Whittemore J. L. Coolidge	1
01-02	Differential and Integral Calculus (1st)	Osgood Bouton	1
01-02	Modern Methods in Geometry.—Determinants	Whittemore	1
02-03	Elements of Mechanics	Whittemore	1
02-03	Differential and Integral Calculus (2nd)	Osgood	1
03-04	The Calculus of Quaternions (1st).—Elementary Principles and Applications	J. M. Peirce	1
03-04	Dynamics of a Rigid Body	Byerly	0.5
03-04	Trigonometric Series.--Introduction to Spheric Harmonics. The Potential Function	Byerly B. O. Peirce	1
03-04	The Elementary Theory of Differential Equations	Bouton	0.5
TOTAL			9

Sources: Kennedy to Kemble, July 26, 1962, ECKP, HUG (FP) 72.10.

Harvard University Catalogue: 1900-1901 (Cambridge, Mass: Harvard University, 1901), pp. 392-395.

Harvard University Catalogue: 1901-1902 (Cambridge, Mass: Harvard University, 1901), pp. 377-381.

Harvard University Catalogue: 1902-1903 (Cambridge, Mass: Harvard University, 1902), pp. 392-396.

Harvard University Catalogue: 1903-1904 (Cambridge, Mass: Harvard University, 1903), pp. 426-430.

Table 1-1-3. The Courses Given at the Physics Department which Bridgman Took as an Undergraduate Student, 1900-1904.

YEAR	SUBJECT-MATTER	INSTRUCTOR(S)	NUMBER OF FULL COURSES
00-01	Experimental Physics.—Mechanics, Sound, Light, Magnetism, and Electricity.	Sabine McElfresh	1
01-02	Electrostatics, Electrokinematics, and parts of Electromagnetism	B. O. Peirce Ayres	1
02-03	Electrodynamics, Magnetism, and Electromagnetism	G. W. Pierce T. Lyman	1
02-03	Electric Conduction in Gases with special reference to the Theory of Ions	T. Lyman	0.5
02-03	Radiation	G. W. Pierce	0.5
03-04	Light and Heat.—Lectures and laboratory work in Thermometry and Physical Optics	Sabine	1
03-04	Elements of Thermodynamics	E. H. Hall	0.5
03-04	Modern Development of Thermodynamics	E. H. Hall	0.5
TOTAL			6

Sources: Kennedy to Kemble, July 26, 1962, ECKP, HUG (FP) 72.10.

Harvard University Catalogue: 1900-1901 (Cambridge, Mass: Harvard University, 1901), pp. 403-405.

Harvard University Catalogue: 1901-1902 (Cambridge, Mass: Harvard University, 1901), pp. 389-391.

Harvard University Catalogue: 1902-1903 (Cambridge, Mass: Harvard University, 1902), pp. 404-407.

Harvard University Catalogue: 1903-1904 (Cambridge, Mass: Harvard University, 1903), pp. 438-440.

Table 1-2-1. The Courses Bridgman Took as a Graduate Student, 1904-1908.

SUBJECT	NUMBER OF FULL COURSES
Mathematics	3.5
Physics	6.5
TOTAL	10

Source: Kennedy to Kemble, Sept. 4, 1962, ECKP, HUG (FP) 72.10.

Table 1-2-2. The Courses at the Mathematics Department Bridgman Took as a Graduate Student, 1904-08.

YEAR	SUBJECT-MATTER	INSTRUCTOR(S)	NUMBER OF FULL COURSES
04-05	Infinite Series and Products	Osgood	0.5
04-05	The Theory of Functions	Bôcher	1
05-06	Methods in Mathematical Physics.—Elasticity; Capillarity; the Theory of the Tides; the Application of the Lagrangian Equation to Problems in Electromagnetism	B. O. Peirce	1
06-07	The Linear Differential Equations of Physics	Bôcher	1
TOTAL			3.5

Source: Kennedy to Kemble, Sept. 4, 1962, ECKP, HUG (FP) 72.10.

Harvard University Catalogue: 1904-1905 (Cambridge, Mass: Harvard University, 1904), pp. 410-415.

Harvard University Catalogue: 1905-1906 (Cambridge, Mass: Harvard University, 1905), pp. 409-415.

Harvard University Catalogue: 1906-1907 (Cambridge, Mass: Harvard University, 1907), pp. 487-492.

Harvard University Catalogue: 1907-1908 (Cambridge, Mass: Harvard University, 1908), pp. 382-386.

Table 1-2-3. The Courses at the Physics Department Bridgman Took as a Graduate Student, 1904-1908.

YEAR	SUBJECT-MATTER	INSTRUCTOR(S)	NUMBER OF FULL COURSES
04-05	The Theory of Probability and the Kinetic Theory of Gases	E. H. Hall	0.5
04-05	The Mathematical Theory of Electricity and Magnetism	B. O. Peirce	1
04-05	Light and Heat	Sabine	1
05-06	The Mathematical Theory of Electricity and Magnetism (2nd)	B. O. Peirce	1
05-06	Light and Heat	Sabine	1
06-07	Light and Heat	Sabine	1
07-08	Light and Heat[1]	Sabine	1
TOTAL			6.5

Source: Kennedy to Kemble, Sept. 4, 1962, ECKP, HUG (FP) 72.10.

Harvard University Catalogue: 1904-1905 (Cambridge, Mass: Harvard University, 1904), pp. 416-419.

Harvard University Catalogue: 1905-1906 (Cambridge, Mass: Harvard University, 1905), pp. 416-419.

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[1] In the letter from Sargent Kennedy to Kemble, Sept. 4, 1962, ECKP, HUG (FP) 72.10, it is reported that Bridgman took "Physics 20d" whose subject-matter was "Topics in the Theory of Functions." According to *Harvard University Catalogue: 1907-1908*, however, Physics 20d was a course on "Light and Heat," while Mathematics 20d was on "Topics in the Theory of Functions." These courses were courses of research, usually taken by graduate students majoring these fields. It seems plausible that Bridgman took Mathematics 20d, especially when one takes into account the fact that he published a paper titled "On a Certain Development in Bessel's functions" (*Philosophical Magazine*, 16 (1908), pp. 947-948) in 1908. Nevertheless, it may be safer to judge that the course was Physics 20d on "Light and Heat" on the ground that he had been taking the same class for the previous three years at the Graduate School.

Harvard University Catalogue: 1906-1907 (Cambridge, Mass: Harvard University, 1907), pp. 493-496.

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