IGNORED INTELLECT

Pierre Duhem

Historical and personal circumstances blocked the career of this right-wing, royalist, religious extremist despite a variety of important contributions. His work is now gaining greater recognition.

by Donald G. Miller

THIS YEAR MARKS the 50th anniversary of the death of Pierre Duhem, one of France's greatest intellects. His work encompasses thermodynamics, physical chemistry, hydrodynamics, elasticity, electricity and magnetism as well as the history and philosophy of science. In his 32 years of scientific activity, he published without collaborators more than 350 papers and 21 books for which a nearly complete bibliography exists.[1] (Some of the work is in many volumes, some in several editions, and some in translation.) His work in the philosophy of science[2,3] has received continuing attention. His work in the history of science in the middle ages[4,5] is well known to historians of science.

Until recently, however, his purely scientific work was almost completely ignored or forgotten by working scientists, with the exception of the Gibbs-Duhem and Duhem-Margules equations, well known to physical chemists. In view of his enormous scientific output, particularly valuable in hydrodynamics, elasticity and thermodynamics, it is curious that this work is so little known.

Why, for example, did Duhem spend his life in academic exile, denied promotions and salary increases, and ostracized by most French scientists? Why in fact did he never get a position in Paris, with its better libraries, better students and all the accompanying prestige, which would have been expected as an appropriate award for his accomplishments? The reasons—scientific, political, and religious—make an interesting story, not without parallels today.

PHILOSOPHICAL OUTLOOK

Duhem belonged to the Energeticist school along with Ernst Mach, Georg Helm, and Wilhelm Ostwald. Duhem's views on the nature of physical theories were similar to theirs and to Henri Poincaré's. In common with them, he believed that physical theories serve as descriptions that condense and classify the results of experiments, rather than as explanations or interpretations of experiment. However, he differed from the others in believing that as physical theories evolve by successive adjustments to conform to experiment, they approach asymptotically a sort of "natural classification" that somehow reflects an underlying reality.[2,3] This view removes him from the ranks of the positivists.

Another point emphasized by Duhem was the impossibility of a truly "crucial experiment." An experimental test of one proposition necessarily involves all the other propositions of the theory. Therefore the contradictions of a theory by experiment can be removed not only by changes in the one proposition believed to be "crucially" tested, but by changes in the other propositions leaving the "crucial" one unchanged.[2,3]

Duhem arrived at the description position more or less in the following way. In the period 1850–1910, there were two opposing viewpoints: one that theories should be based on experiment and description, the other that all of physics could be reduced to classical mechanics and explained by atomic and molecular models. Duhem's scientific formation took place in the period 1880–1890, well before the discovery of radioactivity and the experiments of Jean Perrin or Henry G. J. Moseley. At this time, the group using atomic and molecular models for their "mechanical explanation of the universe" changed the properties of their "billiard balls" at will depending on the phenomenon. These properties, often contradictory, were as hard to believe in then as they are now. Duhem, with his passion for logic, could not accept such contradictory models. He became convinced that on the contrary, instead of having all of physics reduced to classical mechanics, classical mechanics itself was a special case of a more general continuum theory.

Therefore along with the other Energeticists, Duhem believed a gen-

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eralized thermodynamics was the underlying descriptive theory for all of physics and chemistry. He spent his scientific life trying to build up such a generalized thermodynamics, which would include mechanics and electricity and magnetism as well. These attempts culminated in the work *Energétique*,[6] in which however he was unable to include electricity and magnetism. This valuable book, which Duhem himself believed to be his most important and lasting contribution to science, is interesting in that there is not a single word about atoms and molecules.

HISTORICAL STUDIES

That Duhem is known to historians of science is not surprising. He discovered, essentially single-handed, the science done in the middle ages. Besides *Le Système du Monde*[4] and *Léonard de Vinci*,[5] he wrote on the development of mechanics[7,8] and of theories of heat.[9] He began his historical studies hoping to find how gropings and changes in a theory would lead to the "natural classification" mentioned earlier.

Duhem's principal contributions to the history of science were his findings that (a) the middle ages were not in fact dark ages for science; (b) an unbroken thread of physics was carried on from about 1200 to the renaissance, principally within the Church since there was little learning outside of it; and particularly important (c) this science was known to da Vinci and Galileo. Duhem hit upon this by recognizing in da Vinci's notebooks statements by earlier writers and references to manuscripts fortunately available in the Bibliothèque Nationale. These discoveries, supported by quotations from the original texts given in detail in *Le Système du Monde*, completely revolutionized the study of medieval science. Recent studies have resulted in revision of certain details, but Duhem's main findings remain unimpaired.

SCIENTIFIC WORK

Duhem began his scientific work with the generalization and application of thermodynamics. Exploiting the analogy between the potential of classical mechanics and the more general "thermodynamic" potentials of F. J. D. Massieu and J. Willard Gibbs (that is, the Gibbs and Helmholtz free energies G and A), Duhem treated a number of subjects systematically; for example: thermoelectricity, pyroelectricity, capillarity and surface tension, mixtures of perfect gases, solutions in gravitational and magnetic fields, osmotic pressure, freezing points, stability of equilibrium, and the generalization of Le Châtelier's principle. His success with these problems in the period 1884–1900[10a] rank him with J. H. Van't Hoff, Ostwald, Svante Arrhenius, and Henri Le Châtelier as one of the founders of modern physical chemistry.[10b]

Contained in his thermodynamic work is a long critical study of the first and second laws, which for that period includes an excellent set of axioms for thermodynamics.[11] Another paper contains an early attempt to treat a system equivalent to a liquid crystal.[12]

The same continuum-theory outlook permeated his work on hydrodynamics[13] and elasticity.[14] One of his principal results was that a true shock wave (that is, with a discontinuity in velocity) cannot be propagated through a viscous fluid, although there exist quasi shock waves with rapid changes of velocity across a thin layer if the fluid is only slightly viscous. Such questions treated by Duhem 60 years ago have become important recently and we find his hydrodynamics book[13] reprinted by the Ministère de l'Air of France.

A large portion of Duhem's writings are on electricity and magnetism and his attempts to bring them into the framework of Energetics. If the system's electrodynamic energy is constant, Energetics can be successfully applied. If not, then there are complications that require choosing some electromagnetic theory. Although Duhem accepted Maxwell's genius, he could not accept Maxwell's theory because of the contradictions contained in its unrigorous development, its sign mistakes, and its lack of experimental foundation. Duhem preferred a more general electromagnetic theory due to Hermann von Helmholtz, which could be constructed in a logical way from the classical fundamental experiments of electricity and magnetism. This theory, which Duhem helped elaborate, can also describe the electromagnetic theory of light and the experiments of Heinrich Hertz at the expense of some complication. Moreover, it can be shown that Maxwell's theory is a special case of Helmholtz's by choosing appropriate values of two constants. Duhem was a pitiless critic of Maxwell's theory, claiming not only that it lacked rigorous foundation but that it was not sufficiently general to explain the existence of permanent magnets.[15] Duhem later admitted that not only had his criticisms not been accepted; they had not even been read or discussed, and of course Maxwell's theory has triumphed.

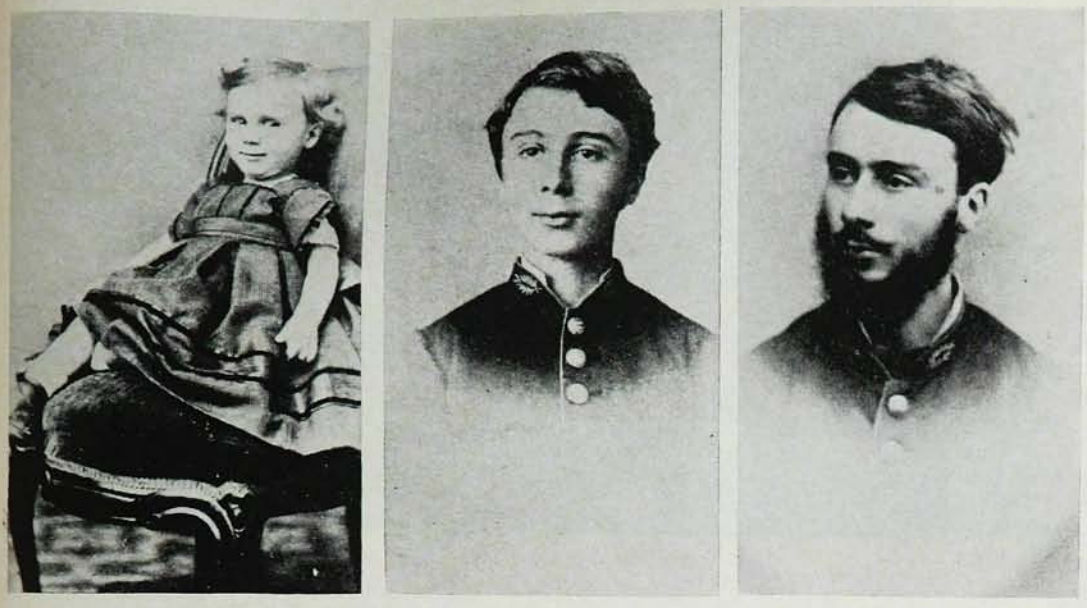
Duhem attached great importance to his thermodynamics of false equilibria.[16] False equilibrium corresponds to Gibbs's "passive resistance" and to "metastable" equilibrium. It characterizes substances such as diamond or petroleum that are unstable thermodynamically with respect to other substances, yet have remained unchanged for geological periods of time, but which will transform into the stable products if the perturbations are large enough. False equilibrium can also be interpreted, however, as a case of extremely slow reaction rate, and a violent polemic over this issue took place between 1896 and 1910. Most, but by no means all, of those interested in such questions prefer the infinitely-slow-reaction-rate view today. Since essentially the same results come from either viewpoint, the choice is a personal one.

Until recently, almost all of this work had been completely ignored. However, in the last few years Duhem's contributions to hydrodynamics particularly have been receiving increasing attention, and a number of people now publishing in the *Archive for Rational Mechanics and Analysis* cite Duhem quite regularly (for example, C. Truesdell[17]).

LIFE AND CAREER

Pierre-Marie-Maurice Duhem was born 10 June 1861 in Paris, and died 14 September 1916 in Cabrespine.

His father, a commercial representative, was originally from Roubaix in



DUHEM at three, at 12 and as a student at Collège Stanislas where he prepared for his entrance into the Ecole Normale Supérieure in 1882.

French Flanders. His mother, a Parisienne, was of a bourgeois family originally from Cabrespine, a small village in the Montagnes Noires not far from Carcassonne. None of his close relatives had been extraordinarily distinguished. He was the oldest of four children, with a brother and twin sisters; the brother and one of the twins died at an early age.

Duhem was educated privately until he was 11. He then entered the Collège Stanislas, a Catholic lycée, to prepare for the entrance examinations of the Ecole Normale Supérieure and the Ecole Polytechnique, the truly elite schools of France. He was a brilliant student, interested in everything, as good in history, languages and letters as he was in science and mathematics. At Stanislas he was influenced towards science, and in particular towards thermodynamics, by Jules Moutier. His ability in languages, particularly in Greek and Latin, served him well later in his study of medieval scientific manuscripts.

At the conclusion of his studies at Stanislas, it seemed very probable that he could pass the examinations for either of the "grandes écoles." His father hoped Duhem would choose the Ecole Polytechnique because his career would be assured. His mother, being very religious, wanted him to enter the Ecole Normale in humanities because she was afraid that engineering or science would destroy his faith. Duhem's choice was science at the Ecole Normale, indicating a desire for an academic career in science. When the extremely rigorous entrance examinations were over, he was ranked first and considerably above the other students. However owing to a recurrent stomach disorder, he did not enter until 1882.

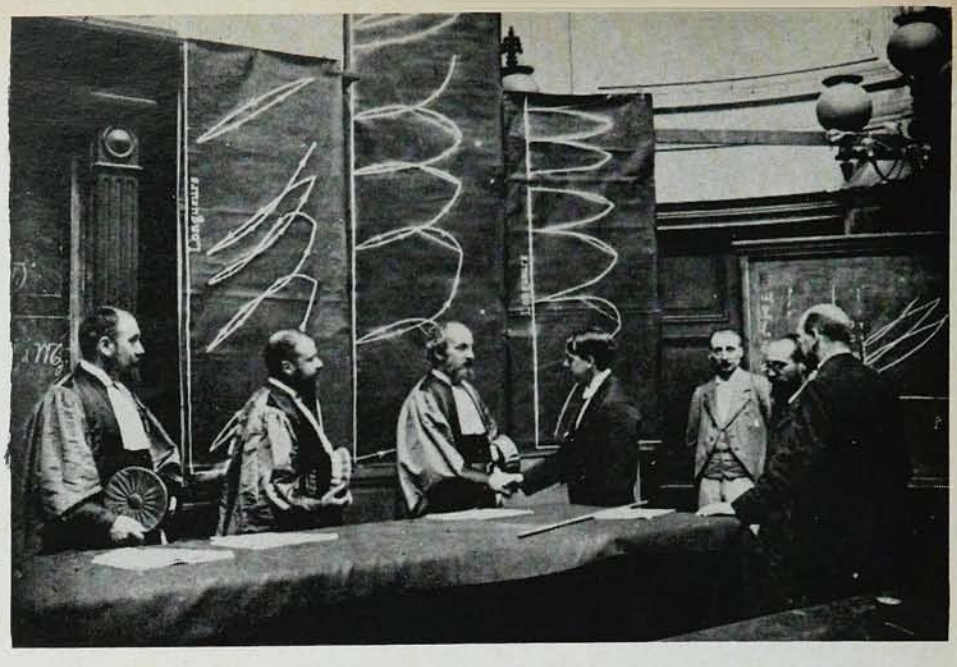
The intellectual stimulation and the possibilities for research at the Ecole Normale made Duhem's years there among his happiest. At the licence examinations in 1885 he was first in physics and in chemistry although only seventh in mathematics (out of 30), but his superiority was so obvious that he was ranked first in his class. At the physics agrégation examination in 1885 he was again first.

Doctoral theses

The usual classwork of a Normalien had not been sufficient for him. His first published paper appeared in 1884 on the subject of chemical potentials. Moreover he presented a doctoral thesis in physics (1884) before he had received his licence (an undergraduate degree).

This thesis was on the application of thermodynamic potentials to physical and chemical problems. It also contained an attack on Berthelot's "maximum-work principle"—which says that the criterion for a chemical reaction to occur is based on the heat of reaction. This "principle" is of course false, since the true criterion is based on the thermodynamic potential. (However, the fact that the maximum-work principle becomes more correct as the temperature goes to absolute zero led Walther Nernst to the third law of thermodynamics.) Berthelot, who had already spent 20 years and was to spend ten more trying to sustain his principle, was extremely influential in official circles and was able to get Duhem's thesis refused. To present such a thesis called for unusual personal courage on Duhem's part. However Duhem believed it had to be done to avoid the spreading of an incorrect thermochemistry, even if it risked stifling his advancement. Therefore after the thesis was refused, Duhem had it published separately as a book,[18] which is important historically for its systematic use of thermodynamic potentials in an era when everyone else was using artificial cyclic processes. The enmity of Berthelot and his friends on this issue alone blocked Duhem's career for many years. Berthelot (who was Minister of Public Instruction in 1886–7) is reported to have said that Duhem would never teach in Paris, and was in a position to make that statement true. At that period, and to a lesser extent even now, the best and most influential posts were in Paris.

After the refusal of this thesis, he stayed on at the Ecole Normale for another two years until he had prepared a second thesis, this time for a doctorate in mathematics on the theory of magnetism. This thesis was accepted in 1888. During his five years at the Ecole Normale, he published 30 papers and one book. In his last two years, Duhem was invited by Louis Pasteur to join his famous group. But Duhem was too committed to physics



PRESENTING A THESIS, that of Paul Saurel, a graduate of the College of the City of New York, in 1900. Left to right are Marchis, Duhem, Brunel (dean), Saurel, Chevallier, Malus, Lenoble.

to accept this opportunity for an assured career.

In 1887, Duhem was appointed maître des conférences in the Faculté des Sciences at Lille. It was a stimulating atmosphere and his ideas on Energetics began to take shape. His extraordinary ability as a teacher became evident, and students flocked to his courses, impressed by a professor who cared about them. While at Lille, he met Adèle Chayet and they were married in October, 1890. Their first daughter Hélène was born in September 1891, but Mme Duhem and their second daughter died in 1892. Duhem's married life had been very happy but tragically short. He never remarried, thereafter devoting the rest of his life to his work and his daughter.

Shortly after the death of his wife, he fell into disagreement with the dean over how severely a laboratory assistant should be reprimanded. During the altercation, the two former friends came to blows. Thus in 1893, Duhem requested a transfer. In the six years he was at Lille, he had published three books and 50 papers.

By this time, his brilliance, ability and further promise were clearly evident, and in ordinary circumstances these would have earned for him a position in Paris. But the opposition, among others, of Berthelot and Le Châtelier (with whom Duhem had had a priority fight) prevented such an appointment, and Duhem was named maître des conférences at Rennes. This situation was so bad that after one year Duhem requested a change.

In exile

Once again a position in Paris was expected, but instead he was appointed chargé de cours at Bordeaux. This terribly disappointing setback caused Duhem to consider refusing the post. His friends, after discreet inquiries, told him that he must realize that Bordeaux was really the road to Paris. Therefore he accepted the position in 1894. In 1895 at the age of 34 he was appointed professor de physique in a chair changed to theoretical physics for him. He was to stay in exile at Bordeaux the remaining 21 years of his life, cruelly disappointed, never to attain his ambition of teaching in Paris.

Duhem's ability as a teacher, evident at Lille, became almost legendary. His courses and public lectures were models of organization and lucidity, exhibiting the precision, logic and attention to detail that characterized his writings. He worked on university affairs for a while until personal attacks by anticlerical members of the university administration caused him to resign from the Conseil de l'Université. He had been primarily responsible for the regulation permitting provincial universities to grant doctoral degrees for theses prepared in the provinces, which had formerly been sent to the Sorbonne. His isolation in Bordeaux limited the number of good students. The most prominent of them was Lucien Marchis, and the most prominent of his disciples and admirers were Emile Jouguet and Louis Roy. Duhem also influenced Jacques Hadamard, and in particular introduced Hadamard to Hogoniot's work on waves.

In 1900, he became a correspondant to the Académie des Sciences (Section de Mécanique) and in the course of years became a member of several foreign academies of science and received two honorary degrees. Although it was clear that his work was of very high quality, and had been honored abroad, Duhem was not recognized by the French Académie because at that time its members had to be in Paris. However when a class of six nonresident members was created in 1913, Duhem was among the first six elected. All earlier proposals to bring him to Paris and elect him to the Académie had met with uncompromising opposition.

Duhem's interests fell roughly into periods. His work in thermodynamics and electromagnetism was predominantly in the period 1884–1900; he returned to the latter between 1913 and 1916. His interest in the philosophy of science was mostly between 1893 and 1906, and the history of science primarily between 1904 and 1916, although his earliest papers date from 1895. Finally he concentrated on hydrodynamics and elasticity between 1900 and 1906.

His tremendous output was in part due to regular, methodical work. He relaxed by walking and reflecting. Once his ideas were well in mind, he sat down and wrote steadily, filling page after page without stopping, without erasures or words crossed out. At his death, he left complete manuscripts ready to be printed, but no

notes whatsoever. (These manuscripts were the last five volumes of *Le Système du Monde*, which were finally published in 1954–59 after 40 years of unceasing efforts by his daughter, Hélène Pierre-Duhem. The only remaining manuscript is 17 chapters on the history and applications of capillarity theories, written several years before his death.)

After his daughter grew older and left for Paris to finish her education, Duhem lived alone in Bordeaux, working steadily. He saw his daughter during vacations, which he spent either at the house inherited from his mother or in hiking over various parts of France by himself or with an old friend. On these trips he would sketch the countryside, inking or charcoaling them in later when he wanted to relax from his writings. These landscapes are extraordinarily well done. He showed this pronounced artistic ability as a boy, and gained a great reputation at Collège Stanislas and the Ecole Normale as a caricaturist.

His life passed in this way: a mounting pile of publications, perusal of medieval manuscripts, vacations in the mountains or at Cabrespine, and some charitable works. As a result of the almost universal scientific and sometimes personal ostracism he suffered, Duhem had withdrawn from most social contacts. The lack of students even for the licence and his personal difficulties with the university administration caused him to reduce his contact with the university to his course hours only. In 1913, however, when he was elected a nonresident member of the Académie, this belated recognition, supported finally even by some of his old enemies, pleased him enormously. Thereafter his personality seemed to bloom again, and his social contacts increased. He became interested in the Catholic students' association and was active in a widows' and orphans' aid society after World War I started.

In the summer of 1916, Duhem and his daughter went to Cabrespine as usual for their summer vacation with the usual program of work, hiking, and sketching. During the evening of 2 September, after a rather strenuous hike, Duhem suffered a painful heart attack. The heart condition had undoubtedly originated in an attack of rheumatic fever he had had as a child. The doctor diagnosed it as angina, the symptoms of which had been present for six or seven years, but had been mistaken for the lifelong stomach cramps Duhem had suffered. Duhem resigned himself to the prescribed rest and limited activity. On the morning of 14 September, he felt somewhat better. However, while inking in a drawing and talking to his daughter about the war he had another attack and died within a few minutes, prematurely, aged 55, leaving unfinished the erudite *Système du Monde*. He is buried in Cabrespine.

REASONS FOR OPPOSITION

Certainly Duhem's promise was evident while he was a student, and under ordinary circumstances, in view of his high-quality work and foreign honors, he would have been called to Paris and been elected to the Académie in 15 to 20 years. Why was he not?

The reasons for Duhem's difficulties involve certain aspects of Duhem's personality as well as differences between scientific schools.

Personality

Duhem was absolutely honest and had firmly held opinions. He prided himself on his independence, as evidenced by the publication of his refused thesis. He always protested vigorously things he believed unjust. He never feared a polemic, was a savage critic, and chose his adversaries without regard to rank or reputation; an example was the fight with the dean at Lille. Another example can be found in one of his attacks on the maximum-work principle where he pictures Berthelot standing among the ruins of his favorite but now discarded scientific ideas, listening to faint murmurs in the background whispering about these men who "seemed during their lives to be something, and now no one speaks of them any more."[19] Those whose writings or teachings Duhem believed to be inimical to science as he conceived it became practically personal enemies.

Ordinarily he was a likable man of perfect courtesy and charm, with many close friends. His students practically adored him. On a person-to-person level, he was conscientious, helpful, and deeply committed to charitable works. However when he saw someone else unjustly treated or he felt his honor or integrity questioned, he would unhesitatingly rise to attack and fight with the verve characteristic of his battle with Berthelot. In such circumstances, even his friends admitted that he sometimes went too far. Such attitudes did not "win friends and influence people," and it has been said that he and his adversaries "ont fait la science avec l'épée." It is possible that the painful writer's cramp he developed at age 40 and the very painful stomach cramps he suffered from all his life contributed to his sharpness and asperity.

Moreover Duhem was a sincere, believing Catholic who deeply resented the liberal, anticlerical nature of the Third Republic. His political views were to the far right. He was a royalist, antidemocratic and anti-Republic, opposed to universal suffrage, and even to the Christian Democratic movement. He had all the prejudices of the higher bourgeoisie, an inheritance from his mother and her family, believing completely in the "natural superiority" of the upper classes, the Church, and the army. Since the Dreyfus case was fundamentally a struggle of these groups versus the Republic and liberal thought, it is not surprising to find Duhem an anti-Dreyfusard almost to the bitter end. Along with the other inherited prejudices of his family he was antisemitic. Nevertheless he maintained friendly relations with his Jewish comrades from the Ecole Normale, such as Jacques Hadamard, all his life, and many of his close friends were Dreyfusards.

Political and religious convictions of this kind were in complete contrast with those held by most of his colleagues and were especially offensive to the free thinkers and liberals who dominated French science and education at that time. Thus a public conflict over the Dreyfus case resulted in a bitter personal hatred between Duhem and certain members of the University of Bordeaux administration. It is also very likely that the scientific antipathy between Berthelot and Duhem was accentuated by such political

and religious differences. (For example Berthelot was a great mechanist champion in the mechanism-vitalism controversy, a controversy with important philosophical and religious overtones.) There is no doubt that Duhem's advancement was retarded in part by opposition to his political and religious views, a phenomenon reminiscent of the treatment of left-wing American scientists in the recent past. In addition to keeping him in exile in the provinces and limiting his salary, the opposition also took the form of a partial conspiracy of silence. His work, though popular abroad, was ignored or else taken over without citation in France. It is curious that even after 50 years there is much more interest now in other countries in Duhem's work, particularly in the United States, than there is in France.

In the face of all this opposition, Duhem was characteristically self-effacing, never complaining of his trials. He did nothing to aid his advancement. He refused to engage in academic politics, and he would not make the expected visits to the influential members of the Académie. He was clearly a man of principle; he refused to be nominated for the Legion of Honor in 1908 because it would have been given by the Republic he hated and signed by a man he detested. Similarly, when later in his life he was urged to be a candidate for a History of Science Chair at the Collège de France in Paris, he refused, saying that he could not enter Paris by a back door; he was a physicist and only as a physicist would he go to Paris. When he was nominated as a non-resident member of the Académie in 1913, characteristically he tried to withdraw so that the next closest candidate, a 90 year old naturalist, could be elected before dying. Even his enemies conceded that he wanted to be in Paris not for the usual reasons of prestige, but because his scientific influence would have been greater there than in Bordeaux.

Scientific opposition

Apart from the opposition based on personal antipathies, there was also the opposition of different scientific schools. In the case of the maximum-work principle, Duhem was right—but the struggle partially ruined his career. However the neglect of portions of his scientific work resulted from the triumphs of theories he bitterly opposed.

For example, the atomic and molecular theories he despised play a much more predominant role in modern science than does generalized thermodynamics, thereby reducing the overall significance of Duhem's contributions. Duhem of course was not alone in his distaste for atomic and molecular models. The Energeticists and many other eminent physicists before 1905–10 did not believe in atoms either. Moreover until the discovery of radioactivity and the experiments of Perrin and Moseley, their belief was not as unreasonable as it may seem now. (One of the most important pieces of evidence for an atomic theory in 1900 was the Law of Multiple Proportions. Hence it is interesting that Ostwald using the work of F. Wald, was able to derive it from the phase rule alone.[20]) Our understanding of atoms is very different today than it was then. Duhem held out against atoms longer than most, because of the characteristic rigidity of his personality, in the hope that a more general theory like Energetics would arise from the ruins of atomic theories.

For a second example, the complete triumph of Maxwell's theory of electromagnetism over the competing Helmholtz theory has naturally left in obscurity Duhem's contributions to the latter. Furthermore Duhem could not accept relativity because he believed it violated "common sense" (a view then shared by many others). Moreover it mutilated classical mechanics in order to leave completely unaltered Maxwell's theory and atomic theories of electrons, both of which Duhem was convinced were erroneous.

The polemical nature of some of his writings in these controversies such as energetics vs atomism, Maxwell's theory vs Helmholtz's, false equilibrium, and the maximum-work principle, made personal enemies of many of his scientific contemporaries. As we have seen, Duhem's work covered many fields, and each one seemed to provide him with a new set of enemies. Thus opposition to him was due not only to Berthelot, who died in 1907. (Berthelot and his friend Lippman were clearly originally responsible for keeping Duhem from a post in Paris. By 1900, however, Berthelot recognized his unfairness and thereafter voted for Duhem's promotions. This change of attitude was appreciated by Duhem who, when ref. 19 was reprinted later without his permission, wrote Berthelot that his permission would have been refused.) Among his other influential enemies according to tradition were Lippmann, le Châtelier and among the atomists, Jean Perrin. (Perrin and Duhem were in agreement however on the falsity of the maximum—work principle.) These and many more tried to block Duhem both on personal and scientific grounds. Although many of his supporters were prominent scientists, they did not hold positions sufficiently influential to help him.

AN ASSESSMENT

With hindsight, it would seem that Duhem should not have so bitterly opposed theories involving models. However his passion for logic and clarity caused him to be repelled by the illogical and self-contradictory models in vogue during his formative years, and he built his whole scientific philosophy on the deliberate avoidance of such aids. Because of the rigidity of his personality, he could not change his views when the models became more plausible and more helpful in new discoveries. The intuitive approach using models or other mental aids are often, but not always, more appropriate in the search for new phenomena. Efforts such as Duhem's towards logical description and unification are usually best for continuum theories that describe phenomena already known. Nevertheless continuum theories have been used recently, as in the past, for the discovery of new phemomena. Today science is concerned with both types of theory, as well as combinations of them.

Although the value of Duhem's historical and philosophical researches have never been in doubt, our description of triumphs of scientific theories that Duhem opposed may leave a negative view of the lasting value of his scientific work. Indeed P. Humbert

said[21] in 1932: "Au fond Duhem a passé sa vie à établir avec un soin extrême la grammaire d'une langue que l'on ne parle plus." ("Fundamentally Duhem spent his life establishing with great care the grammar of a language no longer spoken.")

In my opinion this negative view is not admissible. Even if some of his favorite ideas have been eclipsed by the ascendance of atomic theories, his purely scientific investigations in thermodynamics, physical chemistry, hydrodynamics, and elasticity are important, useful and significant today. Moreover many of his works, particularly in thermodynamics, are of considerable historical importance. In his rejected thesis[18] he showed the great utility of the Gibbs and Massieu thermodynamic potentials in the analysis of practical problems. He was the principal expositor of Gibbs's ideas in France and perfected them in detail.[6, 10a, 11] He helped banish the erroneous maximum-work principle from science, and he gave or anticipated a number of important concepts of thermodynamics. (For examples, we note the first precise definition of a reversible process, the differentiation between quasistatic and reversible processes, the first serious axiomatization of thermodynamics, the definition of heat in terms of work and energy 15 years before Carathéodory, the use of Euler's theorem for partial molal quantities, and a generalized phase rule including masses.) His work on quasi shock waves[13] and systems like liquid crystals[12] is also important.

Pierre Duhem is a fascinating example of a brilliant scientist fearlessly adhering to his views, who was caught up in historical and personal circumstances that blocked his career and partially suppressed his scientific work. Practically a right-wing, royalist, antisemitic, anti-Republic, and religious extremist, he was exiled to the provinces and his scientific work almost systematically ignored in France owing to opposition to his unpopular political and religious views, as well as to his scientific positions.

In my opinion Duhem's scientific work, although ignored until recently for interesting but invalid historical reasons, now deserves more recognition. There is of course no question about the importance of his work in the philosophy and history of science. Since his contributions to any one of the fields of pure science, philosophy or history would have done credit to one person, the ensemble from the pen of a single man marks Duhem as one of the greatest intellects of his period.

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Existing biographical literature[21-25] has of course been drawn upon heavily. In addition considerable useful information has been obtained from a number of people, including J. Hadamard, A. Massoulier, N. Dufourcq, D. Cot, R. Taton, and E. Bauer. I am especially grateful to Hélène Pierre-Duhem for the invaluable information about her father's life and career so graciously given to me in several personal interviews. This work was done in part during the tenure of a Fulbright Fellowship in France 1960-61, in part under the auspices of the U.S. Atomic Energy Commission, and in part with the aid of a grant from the Research Committee, University of California at San Diego. This paper has been adapted from a more detailed manuscript being prepared for publication elsewhere. □

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