

“PLUS COMMUNE ET PLUS ELEGANT”: THE PARIS SCHOOL OF ORGANIC REACTION MECHANISMS IN THE 1920’S AND 1930’S.

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Research on organic reaction mechanisms was an important aspect of the development of physical organic chemistry in the decades of the 1920’s and 1930’s. The experiments and ideas of Christopher Ingold were instrumental in defining this field of research, indeed in establishing the very vocabulary and thought patterns required for talking about structure and mechanism in organic chemistry.

Much less well-known than Ingold’s school, or than competing groups like Arthur Lapworth’s and Robert Robinson’s laboratory at Manchester, is another research school in organic reaction mechanisms centered in the Ecole Normale Supérieure in Paris during the 1920’s and early 1930’s. It was directed by the French chemist Robert Lespieau. Among the most important students and collaborators in this school were Albert Kirrman, who taught at Strasbourg and Bordeaux before returning to Paris in the 1950’s, and Charles Prévost, Kirrman’s closest friend, who returned to Paris in 1937, after having taught at Nancy and Lille. Kirrman and Prévost were perhaps the most influential figures in organic chemistry in Paris from the mid-1930’s through the mid-1950’s.

The aim of this paper is to summarize briefly some of the principal aspects of this Parisian research school, as it existed in the 1920’s and early 1930’s. A short history of the Paris school is important in order to understand the character of physical organic chemistry in France between the wars. This history also is important, as I note in the conclusion of this paper, for the light it sheds on contrasts, as well as similarities, between the

experimental practice and theoretical style of chemistry in France and in England.

Robert Lespieau and the Reform of French Chemistry

Robert Lespieau (1864-1947), director of the chemistry laboratory of the Ecole Normale Supérieure from 1904-1934, was born into a family with strong military ties. The family had considerable political connections, including links with Armand Faillières, at one time President of the French Republic(1). Lespieau brooked family tradition in 1886 by entering the Ecole Normale Supérieure rather than military schools or the Ecole Polytechnique(2).

His intellectual interests lay in the physical sciences, especially chemistry, but he found absolutely uninspiring the chemistry taught by protégés of Marcellin Berthelot in the late nineteenth century. Until 1891 the stubborn Berthelot and his acolytes still were writing water as HO, and, as late as 1898, Berthelot continued to write benzene as C_2H_2 (C_2H_2) (C_2H_2) rather than as a structural or ring formula. There is not the least use of structural formulas in Berthelot’s discussions of isomerism in a 1901 text on hydrocarbons(3).

Successfully learning how to negotiate the perils of this outmoded French chemical notation on his examinations, Lespieau passed the predoctoral exams in physical sciences and then spent two years working with the more up-to-date organic chemist Charles Friedel, who had succeeded Adolphe Wurtz at the Sorbonne(4). To his interest in the new physical chemistry of the late

nineteenth century, Lespieau added a passion for the recent stereochemistry of the Dutch chemist Jakobus van't Hoff and the non-academic French chemist Achille LeBel. In 1892 Lespieau presented a lecture at Friedel's laboratory on the kinetics of tautomerism, using the hypothesis of the tetrahedral carbon structure. This approach led him into a doctoral thesis which included the preparation of stereoisomers(5), and when he completed his dissertation in late 1896, his public defense attracted a considerable audience because he was regarded as a representative of "current chemistry"(6).

The Practice of Organic Chemistry at the Ecole Normale, 1904-1934

By 1904 Lespieau was appointed director of the chemistry laboratory at the Ecole Normale Supérieure, and he radically changed its direction. At the time he was appointed, the best work in French organic chemistry was being accomplished mostly outside Paris, by chemists who had been hostile or indifferent to Berthelot's tutelage, notably Paul Sabatier at Toulouse and Victor Grignard at Lyon and Nancy. They shared a Nobel Prize in 1912 (7).

Under Lespieau's directorship, the primary research program at the Ecole Normale chemistry laboratory became the synthesis and study of nonsaturated organic compounds, along with the application to hydrocarbons of physical methods like François Raoult's techniques using boiling points and melting points. Most of Lespieau's students worked on research topics having to do with isomerism, unsaturated hydrocarbons, or catalysis, often focussing on reactions associated with double and triple bonds (8). His laboratory was open to the students of his colleague Jean Perrin in physical chemistry, and by the 1920's, to students of Albin Haller in organic chemistry, Georges Urbain in general chemistry, and André Job in inorganic chemistry. Collaborating with his former student Maurice Bourguel, Lespieau became one of the first chemists in France to apply Raman spectroscopy to organic analysis (9).

In 1922, the title of Lespieau's position became "professeur de théories chimiques" (10), perhaps the first professorship of "theoretical chemistry" anywhere. There was not a chair of theoretical chemistry in England, for example, until 1931 (11). That Lespieau wanted to have this "theoretical" title demonstrates his self-consciousness about the need for chemical "theory," not just chemical empiricism, in order to renew French chemistry. He had the sense that he was putting organic chemistry at the Sorbonne and the Ecole Normale on a new and different track. By 1922, too, he had two new

students, Kirmann and Prévost, who soon were among his best recruits. Let us turn, now, in some detail to the two of them and their work.

Kirmann, Prévost, and the Theory of "Synionie"

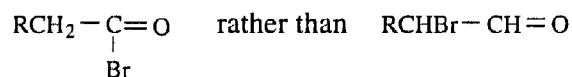
Albert Kirmann (1900-1974) entered the Ecole Normale in 1919 as part of a special group of five Alsatian students permitted to enter *hors concours* because of their status as Alsations whose province now had been restored to the French fatherland. Another student in this special group was Alfred Kastler, who was to receive the Physics Nobel Prize in 1966 for his optical methods of exciting atoms in laser work (12). Kirmann, like Kastler, taught at Bordeaux after completing his doctoral degree in Paris. But Kirmann returned to Strasbourg, where he held a chair in organic chemistry for almost two decades. Protestant by faith, he was nonetheless deported to Buchenwald during 1943-1945 (13). He moved to Paris in 1954, where he ended his career as Professor of organic chemistry, laboratory director, and associate administrative director at his *alma mater*, the Ecole Normale (14).

Charles Prévost (1899-1983), the son of a Parisian engineer, like so many ambitious young French intellectuals, first thought himself to have a vocation as a mathematician after he passed the baccalaureate (15). But introductory exercises in the chemistry laboratory completely reoriented him, and when Robert Lespieau examined him for the certificate in chemistry, Prévost found himself offered a place in Lespieau's laboratory for doing research.

After completing his doctoral thesis, Prévost taught at Nancy and, beginning in 1936, at Lille. The next year he returned to Paris in a specially designated position at the Sorbonne, where he finally received a chair of organic chemistry in 1953. During the Second World War, Prévost remained in Paris, continuing to teach under the Vichy regime. He soon joined the Resistance (16).

As young men who were preparing their doctoral theses in the mid-1920's, Kirmann and Prévost were influenced both by physicists and chemists (17). The physical chemist Jean Perrin presided over the jury for Kirmann's thesis defense (18). By the time Kirmann and Prévost were independently defending their doctoral theses, they had been collaborating in research for several years and had reached the opinion that, while the development of theoretical organic chemistry had not yet arrived at a mathematical stage, the time had come for a qualitative general theory of organic chemistry modelled on physical mechanics (19).

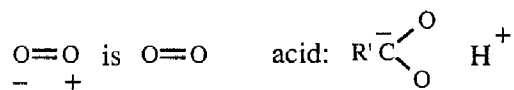
How had they arrived at such a conclusion? In the mid-1920's, Kirmann and Prévost both were working on problems on reactions of unsaturated hydrocarbons, in particular allylic and conjugated systems. Kirmann's research topic became focussed on brominated aldehydes and the so-called "abnormal" reactions in which, for example, these aldehydes behave as if they were acid bromides (20), i.e.



Prévost took for his research project the preparation of derivatives of the alcohol erythritol $\text{C}_4\text{H}_6(\text{OH})_4$ and the study of the mechanism of bromine fixation. Like others, he was struck by what appeared to be anomalies. Thus he obtained a 1,4 dibromide ($\text{CH}_2\text{Br}-\text{CH}=\text{CH}-\text{CH}_2\text{Br}$) instead of the 1,2 dibromide of butadiene. Similarly, instead of obtaining the expected 1,2 dibromide form of divinyl-glycol, he obtained a 1,4 form (21).

In thinking about these reactions, students in Lespieau's laboratory in the mid-1920's were inclined to speculate about intramolecular mobility and migrations not only of atoms or groups within the molecule, but also of electrons which were part of the molecular architecture. These ideas came to them largely through lectures by André Job, who updated students and colleagues on what was happening at the Solvay Institute chemistry conferences in Brussels in 1922 and 1925, the first Solvay conferences in chemistry.

In Job's lectures, and in his own work, Job emphasized reaction dynamics due to inter- and intramolecular "mobilities," as he put it, including the production of unstable intermediate compounds having an electronic or ionic character. We are led to suppose with the English chemist Thomas Martin Lowry, he said, that the double bond is a polarized bond, and that an organic acid is similarly polarized (22):



Lowry, the holder of a newly created chair in physical chemistry at Cambridge University who attended the Solvay conferences, spoke in Paris in March, 1924, on aspects of the theory of valence. He returned to Paris in December, 1925, to lecture on his hypothesis of semi-polar double bonds in organic compounds. These occasions were meetings of the Société de Chimie de France and the Société de Chimie Physique (23).

In speaking to his French audience, Lowry praised the 1916 memoir of the American chemist G. N. Lewis as a "turning point in the history of chemistry" because of its "plausible theory" of the electronic origin of the different types of chemical affinity and its clear differentiation between two kinds of valence: ionic and covalent. It is customary in mineral chemistry, Lowry said, to consider reactions that occur between ions without attaching any importance to ionization in organic chemistry, except for the formation of salts from organic acids (24).

My opinion is otherwise. I consider that 1) certain organic reactants which are the most active are already ionized. 2) Others owe their activity to a possibility of ionization, for example the influence of a catalyst. I conclude that in organic chemistry exactly as in mineral chemistry, reactions take place almost always between ions.

Lowry concluded with a discussion of what he called "dynamic isomerism" which might be of three kinds: transfer of 1) a radical; 2) a hydrogen ion or proton; or 3) an electron. The latter two categories he called "prototropy" and "electrotropy" (25).

There is no question that Kirmann and Prévost were influenced by Lowry's theories for explanation of reaction mechanisms. Another important influence was Georges Dupont, a frequent visitor from Bordeaux, with whom they talked at length in the Paris laboratory and who succeeded Lespieau as director upon Lespieau's retirement. Dupont published a paper in 1927 in which he attempted to combine the electron octet theory of valence and Bohr's hydrogen electron model with classical concepts of stereochemistry. Dupont adopted without reservation Lowry's application of ionic radicals in hydrocarbon chemistry (26).

At the time they were writing their doctoral dissertations, Kirmann and Prévost conceived the idea of developing a general theory of reaction mechanisms in organic chemistry, using principles and notation that Prévost was using in his thesis. They were concerned to take into account the classical tradition of stereochemistry, in particular the notion of the carbon tetrahedron, which commanded pride of place in French organic chemistry. They also wanted to develop ideas compatible with their mentor Jean Perrin's radiation theory of chemical activation. As Prévost and Kirmann put it, their goal was to construct a conceptual edifice "plus comode et plus élégant" than the array of theories presently available in organic chemistry" (27) (i.e., than theories mostly appearing in England and in the United States).

Their joint effort was published in the form of three memoirs in the Bulletin of the Société Chimique de France in 1931 and 1933. The joint publication would have appeared earlier, had it not been for the fact that the manuscript was in press at the time that a fire destroyed the printing house (28). Somehow they recovered their stamina and their text.

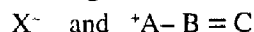
In their introduction to the memoirs, Kirmann and Prévost took pains to state that theirs was not simply a "compilation of . . . memoirs published . . . abroad on the question." They stressed that this was a "purely theoretical work" and that it was new in character, while building on previous hypotheses. They also suggested that chemists' work was providing challenges and guidance to problems which now must be tackled by physicists (29). This notion of collaboration, by the way, was a frequent theme of Lowry.

Their starting point was the fundamental hypothesis that the reactions of organic chemistry are reactions of ions, i.e., that at the moment of reaction, the sections ["tronçons"] of the hydrocarbon molecule possess localized electric charges (30). Physical proof exists for this hypothesis: for example, that with the exception of saturated hydrocarbons, molecules with pronounced chemical reactivity have a permanent electric moment. This was a subject on which Kirmann published a review paper in the *Revue Générale des Sciences* (31).

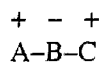
They further argued that the ionized molecule is the "active molecule" referred to in Jean Perrin's recent theoretical work on the energy of activation, and that the energy required to cause the ionization must come from circumstances exterior to the molecule, for example, through the presence of another molecule or catalyst, or from radiation (32). (The radiation theory of activation, by the way, was just then disappearing from the chemical literature.)

The theory they offered rested on a new and more general law, they claimed, than Lowry's notion of "prototropy," which referred to hydrogen or proton migration. They introduced a new term, "synionie," which does not imply the sign of the mobile radical. In particular, Prévost and Kirmann had in mind a principle (or law) and a theory which would cover, in addition to H^+ , the case of hydroxyl (OH^-) and halogen (especially Br^-) migration which they had studied in their research on alcohols and brominated hydrocarbons.

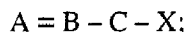
For the molecule of form $X-A-B=C$, the departure of negative X creates the ions:



but this form becomes



by induction, which is also the activated form of



so we say that $X-A-B=C$ and $A=B-C-X$ are two "synionic isomers" (33). An example from experimental work is the existence of the synionic isomers: $CH_3-CHCl-CH=CH_2$ and $CH_3-CH=CH-CH_2Cl$.

They also defined what they called a state of "métaionie" in which none of several structural formulas corresponds to the "real" structure of the reacting molecule. The multiple structural formulas for benzene are examples of their "métaionie" (34).

The general theory of ionization and the new terminology were meant to cover and coordinate three different types of ionic reactive states: the allylic (involving carbon, hydrogen, oxygen, and sulfur), cyanhydric (involving nitrogen), and ring-chain or cyclization (35). In addition, Prévost and Kirmann stressed the problematic character of the electron doublet representation, an "image, certainement fausse," they said, because the doublet does not really have a fixed position, but corresponds "to an average position in the oscillations of which the molecule is the seat." It was through spectroscopy focussed on the infrared spectrum and the Raman effect that they thought the true movement of electrons could be made precise in what they called a future "electro-geometric synthesis" (36).

The "French" and "Anglo-Saxon" Schools of Theoretical Organic Chemistry

The joint memoirs of Prévost and Kirmann self-consciously presented a general theory of organic chemistry which constituted an application of physical methods and principles to the problem of organic reaction mechanisms. However, the language-system devised by Prévost and Kirmann was not adopted by chemists in general, and that part of their notation that was new was not used outside France. Indeed, there was very little interest in their work inside France.

In 1934, the year after the publication of the last installment of the Prévost-Kirmann theory, there appeared in *Chemical Reviews* the paper which was to set up a system of explanation-language for organic reaction mechanisms that became dominant in the next decades. This was Christopher Ingold's "Principles of an Electronic Theory of Organic Reactions," in which the "nucleophilic"/"electrophilic" classification and notation were introduced (37).

Curiously, the Ecole Normale school of chemistry now repeated the history of Berthelot's generation of French chemists, in which many French chemists had persisted in the language and theory of "equivalents" not in use elsewhere. Now Prévost's and Kirmann's "ionic" theory was everywhere else the "heterolytic" theory; their "synionie" was the S_N1 or $E1$ group of reactions. The elsewhere ubiquitous curly arrow and electron octet hardly appeared in French chemical papers and textbooks. Many organic chemists in France found even the Kirmann-Prévost approach too speculative and radical. Victor Grignard wrote in 1935 in his introduction to the multivolume *Traite de chimie organique*(38):

As for the new electronic theories, they are not sufficiently developed for serving as the basis for speculations in organic chemistry, despite all the promises they offer to chemists. In this text, they will . . . remain discreetly in the background; and it is still the very fruitful conception of Le Bel and van't Hoff which will constitute the surest guide for us.

Prévost and Kirmann did little to develop further the theory of "synionie" in the 1930's and 1940's, although Prévost returned to these kinds of issues after an international meeting at Montpellier in 1948 in which Christopher Ingold participated and after a set of four lectures by Ingold in Paris. Prévost remained convinced that the S_N1/S_N2 categories were too rigid and did not adequately describe the nuanced spectrum of electronic mechanisms (39). (Here Prévost reminds the historian of Georges Buffon's objections to Linnaeus' definition of biological species in the eighteenth century.) Prévost's criticism ignored the fact that Ingold's classification was not meant to be a rigorous set of inferential principles, but only a representation of extreme types (40).

Ingold's *Structure and Mechanism in Organic Chemistry* appeared in 1953. It became one of the fundamental handbooks of organic chemists—a piece of classic literature for the discipline of physical organic chemistry. It included both in its text and in its network of citations a history of developments in physical organic chemistry. As in Ingold's paper of 1934, this history made no reference to Prévost and Kirmann, nor to any French theories of reaction mechanisms (41). Prévost and some of his protégés were bitter about this, and they often referred to an "Anglo-Saxon School" of chemistry that ignored French contributions to the theory of reaction mechanisms (42). They nonetheless professed admiration for the work of Ingold, whom Prévost and Kirmann cited as early as 1931 in their joint memoirs (43). In 1954 Prévost proposed Ingold's name to the Nobel Chemistry Committee in Stockholm (44).

After the Second World War, students in French chemistry were to feel that they had lost step with progress in theoretical chemistry elsewhere, especially in the understanding of organic reaction mechanisms and in the application of quantum mechanics to chemical problems. Raymond Daudel began a theoretical chemistry group in 1942, with the patronage of Louis de Broglie, Frédéric Joliot, and A. Lepape, but Daudel was hard-pressed to interest theoreticians in quantum chemistry rather than in quantum field theory or in neutron and high-energy physics. In the CNRS, work which would have been called quantum chemistry elsewhere was carried out in the section for applied mathematics until the 1970's (45).

In 1948, the year that Christopher Ingold lectured on reaction mechanisms in Paris, Edmond Bauer, who was Jean Perrin's successor at the Sorbonne, organized a conference on the quantum theory of the chemical bond, funded by the CNRS and the Rockefeller Foundation. Charles Coulson, Christopher Longuet-Higgins, Michael Polanyi, R. W. Hill, and L. E. Sutton came from England to give papers, as did Linus Pauling and Robert Mulliken from the United States. In 1959 Guy Ourisson renovated the study of organic chemistry in France by organizing the Groupe d'Etudes de Chimie Organique (G.E.C.O.), in order to facilitate contact with chemists abroad and to rethink the theoretical foundations of modern organic chemistry (46). That this was a project still sorely needed in the late 1950's is indicated by Micheline Charpentier-Morize's reflections upon her doctoral thesis defense in 1958. Prévost presided over the jury. When she referred to the possible existence of a " π -complex" in order to explain reactivity, Prévost exclaimed: "Madame, if I have one reproach for you, it is that you know the modern theories too well (47)."

It is striking how isolated French chemists were from what we may now call the mainstream during the decades of the 1920's through the 1950's. Scarcely any French scientists studied abroad. Albert Kirmann was unusual in his decision to spend a year in Munich in 1930, but he had, after all, been born a German in Alsace. J. C. Smith notes in his history of Oxford University's Dyson Perrins Laboratory, directed by Robert Robinson in the 1920's and 1930's, that there was a great mixture in Robinson's lab of ages and nationalities among the twenty students each year, but never, until 1947, a French person (48). This French insularity contributed to the closure of the boundaries of the research school associated with Lespieau's laboratory at the Ecole Normale Supérieure and to its exclusion from the wider disciplinary history of physical organic chemistry and theo-

retical chemistry. Staging international conferences in Montpellier and Paris helped overcome some of this isolation but by no means solved the problem.

Finally, to come back to the title of this paper, and to a characteristic tradition or style in French science, the Paris school defined theoretical chemistry as a kind of chemistry (and a kind of science) that aimed ultimately at abstract knowledge in the purest sense. Historically, in the development of theories about reaction mechanisms and activation in the 1920's, research groups at London, Manchester, Cambridge, and Leeds led the way with imaginative, visually graphic mechanisms based on ideas of corpuscular motions. In contrast, the Ecole Normale school of chemistry tended to avoid visual, corpuscular imagery in favor of more generalized and abstract systems based firmly in empirical descriptions of ionization or radiation. That is, the French school valued most highly the theory that was "plus commode" and especially "plus élégant."

I conclude with Albert Kirrmann's statement of the agenda for organic chemistry in the early 1950's. Fundamental problems of organic chemistry lay, he said, in three areas: the accomplishment of organic synthesis; the elucidation of molecular structure; and the inquiry into reaction mechanisms. The study of mechanisms, Kirrmann wrote(49):

... is, more than that of synthesis, deeply impregnated with the spirit of pure science, of which the unique goal is to know and not to create . . . It is still the case that the achievements of chemistry, in the face of problems of extreme complexity, inevitably are of a qualitative order on the whole, and they appeal exclusively to the *esprit de finesse*. Physics, in contrast, since it is able to limit its parameters, has more easily attained the quantitative stage, and the *esprit géométrique* suffices, on the whole, for it to progress on its way.

So we see that Kirrmann and his colleagues in theoretical chemistry at the Ecole Normale Supérieure still continued to anticipate a future stage of chemical progress when theoretical chemistry, like theoretical physics, would be characterized by *l'esprit de géométrie*. Perhaps neither Kirrmann nor Prévost really ever surrendered the youthful aspiration of the French intellectual to be a mathematician.

ACKNOWLEDGMENTS

With permission of the University of California Press, this essay is taken largely from Chapter Six, "The Paris School of Theoretical Organic Chemistry, 1880-1930," in my book *From Chemical Philosophy to Theoretical*

Chemistry: Dynamics of Matter and Dynamics of Disciplines. 1800-1950, Copyright (c) 1993, The Regents of the University of California. This book considers the work of Christopher Ingold and his associates at some length, as does William H. Brock in *The Norton History of Chemistry*, W. W. Norton, New York, 1993).

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2. G. Dupont, "Robert Lespieau. 1864-1947," *Bull. Soc. Chim. Fr.*, **1949**, [5], 16, 1-9, on p. 1.
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4. Friedel became internationally known for the synthetic method called the "Friedel-Crafts Reaction" using aluminum chloride as a catalyst in the introduction of an alkyl or acyl group into benzene. James Mason Crafts was an American professor from MIT working with Friedel in 1877 at the Sorbonne. Crafts later became president of MIT.
5. R. Lespieau, *Notice sur les travaux scientifiques*, Gauthier-Villars, Paris, 1910, 10-12. The thesis concentrated on compounds of the propylene and propanol series; he prepared two dibrominated propylenes and found stereochemical isomerism in one of them: $\text{CH}_2=\text{CBr}-\text{CH}_2\text{Br}$.
6. Report on Lespieau's thesis, dated October 24, 1896. AN F17/24392.
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9. G. Dupont, "Robert Lespieau," *Bull. Soc. Chim. Fr.*, 1949, 3.
 10. AN F17/24392 (Robert Lespieau) and AN AJ16/5738 (Georges Dupont).
 11. This was the chair of theoretical chemistry held by John Lennard-Jones at Cambridge University, who pursued a very different research agenda from that of Lespieau. Christopher Hugh Longuet-Higgins became professor of theoretical chemistry at Cambridge, succeeding Lennard-Jones, in 1954.
 12. A. Kastler and Y.Noel, in *Hommage à Albert Kirmann*, courtesy of Ecole Normale Supérieure (ENS) Bibliothèque des Lettres; W. Sullivan, "Dr. Alfred Kastler, 81, Nobel-Prize Winner, Dies," *New York Times*, January 6, 1984. Sullivan says there were five students admitted *hor concours*; Kastler says there were eight.
 13. See C. Prévost, "Notice nécrologique. Albert Kirmann," *Bull. Soc. Chim. Fr.*, 1957, 1er partie, 1451-1454.
 14. *Ibid.* Dupont was director of the Ecole Normale, but since professors of letters and sciences alternate in assuming the directorship, Kirmann became vice-director, not director (p. 1452).
 15. C. Prévost, *Notice sur les titres et travaux scientifiques*, Société d'Édition d'Enseignement Supérieure, Paris, 1967, 7.
 16. See P. Piganiol, "Charles Prévost," *Ann. AEENS*, 1985, 46-48, on p. 47.
 17. See Kirmann's remarks in *Hommage à Albert Kirmann*, 1970, and especially on Job, A. Kirmann, *Notice sur les titres et travaux scientifiques*, 1954, p 8, typescript of 20 pages, ENS. Courtesy of ENS Bibliothèque des Lettres. Eugene Bloch taught physics at the Ecole Normale from 1913 on and became professor of theoretical physics and celestial mechanics at the Sorbonne in 1930. He succeeded Henri Abraham, one of Lespieau's old friends.
 18. Ref. 13, p. 1452.
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 23. T. M. Lowry, "Nouveaux aspects de la théorie de la valence," *Bull. Soc. Chim. Fr.*, 1924, 35, 815-837 and 905-921; T. M. Lowry, "Le dispersion rotatoire optique. Hommage à la memoire de Biot (1774-1862)," *J. Chim. Phys.*, 1926, 23, 565-585; T. M. Lowry, "Preuves expérimentales de l'existence des doubles liaisons semi-polaires," *Bull. Soc. Chim. Fr.*, 1926, 39, 203-206. There is an account of the December 11, 1925 lecture, which notes discussion afterwards. Dufraisse, Mauguin, Tiffeneau, and Job were among those present.
 24. T. M. Lowry, "Nouveaux aspects de la théorie de la valence," *Bull. Soc. Chim. Fr.*, 1924, 35, 817.
 25. Ref. 24, esp. pp. 816, 827-828, 834, 836; and 908-909, 917.
 26. G. Dupont, "Sur la théorie électronique de la valence. Essai de représentation stéréochimique des éléments," *Bull. Soc. Chim. Fr.*, 1927, [4], 41, 1101-1137, quotation on p. 1107.
 27. Ref. 19, p. 1368.
 28. The three memoirs are: a) C. Prévost and A. Kirmann, "Essai d'une théorie ionique des réactions organiques. Premier memoire," *Bull. Soc. Chim. Fr.*, 1931, 49, 194-243; b) Ref. 19; and c) "La tautomérie anneau-chaine, et la notion de synergie. Troisième communication sur la théorie ionique des réactions organiques," *Bull. Soc. Chim. Fr.*, 1933, 53, 253-260; quotation from 1931, p. 194.
 29. *Ibid.*, p. 196.
 30. They distinguished the molecule "in repose" from the molecule in action. They also suggested use of circled + and - symbols to indicate "tendency" to charge rather than actual charge. As we will see later, the "curly arrow" and the $\delta+/\delta-$ notation, not their symbols, were to accomplish this notation. See Ref. 28, pp. 201, 208-210.
 31. A. Kirmann, "Le moment électrique des molécules," *Revue Générale des Sciences*, 1928, 39, 598-603. He cites work including that of Paul Langevin on the theory of the Kerr Phenomenon. He also calculates that the average calculated dipole length is on the order of tenths of an angstrom, compatible with the estimated distance of an angstrom between atoms, for example, in hydrogen chloride (p. 602).
 32. Ref. 28a, 197, 200; Ref. 19, 1324, 1339.
 33. Ref. 21, pp. 199-120.
 34. Ref. 28a, pp. 224, 240.
 35. Ref. 28c, p. 253.
 36. Ref., 19, pp. 324-1325. 1357; also Ref. 28c, p. 259.
 37. C. K. Ingold, "Principles of an Electronic Theory of Organic Reactions," *Chem. Rev.*, 1934, 15, 225-274.
 38. V. Grignard, Ed., *Traité de chimie organique*, Masson, Paris, 1935, Vol. I, pp. x-xi.
 39. Conversation with Professor Georgoulis, Paris, June 11, 1987; see also Ref. 15, p. 13.
 40. See D. W. Theobald, "Some Considerations on the Philosophy of Chemistry," *Chem. Soc. Rev.*, 1976, 5, 203-213, on p. 213.

41. C. K. Ingold, *Structure and Mechanism in Organic Chemistry*, Cornell University Press, Ithaca, NY, 1953.
42. Prévost refers to the "Anglo-Saxon School" often, for example in "La valence et l'enseignement," *L'Information Scientifique*, 1951, 6, 14-18, on pp. 15-16: "We must keep those teaching methods which are good . . . in guarding against our falling into the exaggerations of the Anglo-Saxon School which from the start sacrifices descriptive chemistry, the solid part, to 'up-to-date' [original in English] theoretical chemistry which is less definitively established." Pierre Piganiol wrote in his obituary notice for Prévost, "After the war . . . the foreign schools [of chemistry] took the lead, and British 'fair-play' [original in English] proved more a myth than a reality in this regard." (Ref. 16, p. 47.)
43. Prévost and Kirrmann cite Ingold's experiments providing evidence of the inadequacy of Lapworth's and Robinson's theory of alternate induced polarity in their 1931 memoir, p. 1320. Their reference is to C. K. Ingold, *J. Chem. Soc.*, 1930, 1037.
44. Letter from Ingold to Prévost, dated July 29, 1946; and a letter from the Secretary of the Nobel Committees of the Swedish Royal Academy of Sciences to Prévost, January 16, 1954. Copies of these letters were given me by Constantin Georgoulis. Georgoulis completed a doctoral thesis at Paris in 1960 on the kinetic study of reaction schemes for allylic transpositions, under the direction of Prévost. Another of Georgoulis' teachers was Paul Job, the cousin of André Job.
45. Ibid. and R. Daudel, "L'état de la chimie théorique," *Guide Pour l'Exposition présentée au Palais de la Découverte*, Sennac, Paris, 1949, p. 4.
46. M. Charpentier-Morize, *La contribution des 'laboratoires propres' du CNRS à la recherche chimique en France de 1939 à 1973*. No. 4. *Cahiers pour l'histoire du CNRS*, Editions du CNRS, Paris, 1989.
47. Personal correspondence, letter of January 16, 1991.
48. J. C. Smith, in "The Development of Organic Chemistry at Oxford," 2 pts., Robert Robinson Papers, Manuscripts A.6 and A.7, Royal Society of London Library, p. xx.
49. A. Kirrmann, "Aspects actuels de la chimie organique," *Revue Philosophique*, 1966, 156, 53-58.

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located in the village of Rumford in the city of East Providence, RI, is the repository for a wide collection of items—photographs, laboratory notebooks, packaging materials—from the former Rumford Chemical Works, founded by Eben Horsford and a business collaborator in the mid-nineteenth century. The museum is maintained by the East Providence Historical Society, PO Box 4774, East Providence, RI 02916, Edna Anness, Curator.