# *Third Pedler Lecture.*

### DELIVERED ON MARCH 10TH, 1932.

### By LEOPOLD RUZICKA.

## *The Life and Work of Otto Wallach.*

THE honour, which is mine, of speaking here on the life and work of Otto Wallach, who died on February 26th, 1931, is also a task which holds a certain measure of difficulty. Upon only one occasion did I have the good fortune to meet Wallach. In the spring of 1928 a convention of chemists of North-west Germany was held in Göttingen. During one of the lectures a small white-haired man entered the room. " That is Wallach ! " thought I at once. The few words I exchanged with him, and his appearance—the clear blue eyes beaming in his exceedingly fine and sage countenance—made an indelible impression on my memory. A brief meeting such as that cannot replace a long acquaintance. It afforded me, however, an experience of his remarkable personality which, I trust, may supply the mental plastic necessary to cement together the data I have collected from his writings and those of his school.

Wallach was born in Königsberg on March 27th, 1847. His parents' home appears to have had but little direct influence upon his career. This, however, was largely affected by the circumstance that his father, a Prussian official, moved from Otto's birthplace to Stettin and finally to Potsdam, in the vicinity of the German metropolis. There the young Wallach received his elementary schooling, ending with the classical " Gymnasium."

In the higher classes of the school there existed a club for the encouragement of the study of literature and the history of art. Wallach's words make clear the influence which this activity had upon his inner life. " There I felt the first unforgettable urge towards art and its history. This pointed out to me, early in my life, the path leading from the drab plain of life's demands to the stimulating heights of art." Wallach remained true to this youthful inclination, and as one of the advantages of his later home in Bonn he mentions its proximity to the Belgian and Dutch schools of art. Many of his vacation trips were devoted to the study of art, and in his professional home in Göttingen he made a collection of water-colour paintings.

Even during his early school years Wallach evinced a strong interest in chemistry, which, at that time, was not taught as a separate subject in " Gymnasiums," but was treated only in a rather step-motherly fashion as an off-shoot of physics. Like many other rising chemists of that time, he made his first venture into the realm of chemistry under the guidance of Stöckhard's " Schule der Chemie " and with the help of primitive apparatus. " At home," he says, " these experimental tendencies, not always resulting in too fragrant products, found little sympathy, for I come of a great family of lawyers, little interested in the natural sciences." His relatives and friends, therefore, did not greatly sympathise with his choice of profession when he decided, in the spring of 1867, to study chemistry in Göttingen, where Friedrich Wöhler directed the chemical laboratory.

For personal reasons, Wallach passed his second semester in Berlin, whither A. W. Hofmann had just come from London as successor to Mitscherlich. Wallach then returned to Göttingen, where the conditions in the laboratory were definitely more agreeable than in Berlin. Concerning this period he wrote : " There followed a time of restless activity. In Wöhler's laboratory indolence was not tolerated : anyone who did not occupy his working place regularly must expect to receive from the ' Hofrat ' a letter summoning him to vacate it." Work was carried out in the laboratory from seven o'clock in the morning until at least five o'clock in the afternoon; the gas used by the laboratory students was then turned off. " After that hour, in winter, many operations had to be finished by the scanty light of candles which the students had brought with them." So industrious was Wallach that, with the special permission of the " Honourable-Faculty," composed of the fifteen oldest professors, he was able to obtain his Doctor's degree after five semesters of study. His dissertation, carried out under the direction of Hübner, dealt with position isomerism in the toluene series.

The following winter semester brought Wallach to Berlin as assistant to Wichelhaus, who was later to become the well-known technologist. Here he gained valuable stimulus by visiting the German Chemical Society, founded in 1868, where he made the acquaintance of many of his German and foreign colleagues. In the spring of 1870 he accepted an assistantship in Bonn offered to him by Kekulé, who said in his letter : " It will not hurt you to come to Bonn. Here we lead a scientific artist-life."

In the memorial lecture which he delivered in 1897 before the Königl. Gesellschaft der Wissenschaften in Göttingen, Wallach strikingly portrayed Kekulé's individuality. Their different conceptions of " Art " profoundly influenced the lives of the two men. Kekulé, the born artist, long wavered between chemistry and architecture as a profession, and then with the artist's intuition created structural organic chemistry. He continued to work intensively in the field of experimental science for only a few years after Wallach's arrival in his laboratory. "Kekulé was no busy bee," writes Wallach, "constantly endeavouring to enrich the hive of knowledge with the greatest possible number of new cells." Wallach, on the contrary, was the experimental artist : at the age of 80 he was still experimenting in his laboratory on problems that interested him.

Wallach's stay at Bonn lasted for nineteen years, with one brief interruption. For the third and last time he tried to establish himself in Berlin, entering, as its only chemist, a newly founded enterprise which later developed under the name "Aktien-Gesellschaft für Anilin-Fabrikation" (Agfa). The noxious gases of the factory, however, were so detrimental to his weak health that he had to resign his position. He soon found an opportunity of returning to Kekulé in Bonn, where, in the spring of 1872, he took over the position of assistant in the organic laboratory. A year later he became Privatdozent, and in 1876 Extraordinarius. Until then, Wallach had passed through "relatively easy years, free from responsibility," but now followed a period only too well filled with non-experimental work. Kekulé, although remaining director of the Chemical Institute, withdrew more and more from active participation in the laboratory work, and in 1879 the instruction in pharmacy, a foreign field into which he had to initiate himself, devolved on Wallach.

Wallach's scientific work of this period is entirely different from his later famous fields of research : the discovery of the iminochlorides by the action of phosphorus pentachloride on the acid amides may be mentioned as an example.

His new duty had a decisive influence on Wallach's future scientific career, for in teaching pharmacy he had to deal with the ethereal oils. The state of knowledge existing in this field at that time can be best illustrated by a quotation from the introduction of his first publication on the subject (August 10th, 1884) : "The numerous so-called ethereal oils are known to be mixtures, for the most part, of hydrocarbons of the terpene group with oxygen-containing compounds, often closely related to camphor, in which sometimes the oxygen-free constituents, in other cases the oxygenated constituents, preponderate. As a result of the examination of these constituents isolated from ethereal oils, in course of time a large series of compounds of the same composition has been described. These bear different names in accord with their origin, but they have not been examined experimentally to determine whether or not they are really different from one another. Hydrocarbons of the formula $C_{10}H_{16}$, namely, terpene, camphene, citrene, carvene, cinene, cajuputene, eucalyptene, hesperidine, etc., etc., are mentioned in such number that it seems highly improbable that they can all be different substances. It is the same with the corresponding oxygenated products, $C_{10}H_{18}O$, $C_{10}H_{16}O$, etc."

On August 4th, 1909, on the occasion of the fortieth anniversary of his promotion, Wallach's former co-workers held a reunion in Göttingen to celebrate the appearance in Liebig's *Annalen der Chemie* of his hundredth paper concerning the ethereal oils. When returning thanks, Wallach took the opportunity to describe the immediate cause of his original interest in these substances. In a cupboard in Kekulé's private laboratory there had stood for fifteen years several unopened flasks containing ethereal oils, which Kekulé had procured for research purposes but had not used. Kekulé granted Wallach's request for permission to carry out a research on the mysterious contents of the flasks, with the words : " Yes, if you can make anything out of them ! ", accompanied by the ironical laugh that he gave only when he believed someone to be on the wrong track.

The opinion of leading organic chemists in 1884 concerning the ethereal oils was similar to that which had been held very shortly before with regard to the synthesis of closed carbon chains. In May, 1929, in the first Pedler Lecture, William Henry Perkin mentioned that Adolf v. Baeyer, as well as Emil Fischer and Victor Meyer, rated as very slight the prospect of synthesising small carbon rings.

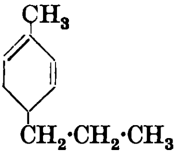
The difficulties which Wallach had to overcome in his first struggles with terpene mixtures were by no means small. But only a year after his first publication he was able to state that " a great many terpenes, formerly designated differently and alleged to be of various constitutions, are undoubtedly identical."

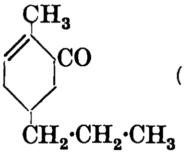
Before we turn to a detailed consideration of Wallach's work, let us cast a glance over what had previously been accomplished by others. The first extensive researches in this field were carried out during the years 1852—1863 by Berthelot, who was particularly successful in working with turpentine oil and its products of rearrangement. He was able to characterise *d*- and *l*-pinene, as well as *d*-, *l*-, and *dl*-camphene, the last of which he obtained by splitting out hydrogen chloride from pinene hydrochloride. He gave different names to the optical isomerides, however, and therefore could not correlate them. To characterise the various pinenes, Berthelot used only the hydrochlorides.

The first insight into the constitution of the terpenes was afforded by their transformation into aromatic compounds. In 1838, by the action of phosphorus pentoxide on camphor, Dumas and Péligot had obtained "camphene," which was, however, nothing other than *p*-cymene. In 1847, Caillot obtained terephthalic acid by the oxidation of turpentine oil with nitric acid. It was then known that terephthalic acid is an aromatic compound, and Caillot pointed out the relation between turpentine oil and the aromatic series, but he had no idea about further details of structure, such as the nature of the side chains.

Another step was taken when Barbier and Oppenheim, independently of one another, in 1872, obtained *p*-cymene by the action of bromine on terpin, which itself resulted from treatment of turpentine oil with sulphuric acid. *p*-Cymene was then supposed to be *p*-methyl-*n*-propylbenzene, and hence Oppenheim assigned the formula (I) to pinene. This formula and that (II) given by Kekulé to camphor illustrate the state of constitutional formulæ at that time.

(I.)



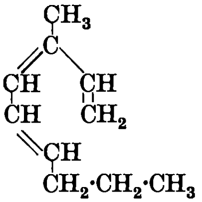


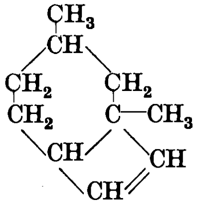
(II.)

A further important observation was made in 1875 by Tilden, namely, the formation of a crystalline addition product from turpentine oil and nitrosyl chloride. Shortly afterwards, he and Shenstone found that the terpenes of the citrus oils also give a crystalline nitrosochloride. Both nitrosochlorides produced nitroso-derivatives by elimination of hydrogen chloride. Accordingly Tilden divided the natural terpenes into two groups : the turpentine and the orange group.

This classification was, however, insufficient, since it was based on too small an experimental foundation. On the other hand, Tilden was right in his prediction that the number of terpenes would prove far less than that which one had assumed from the statements then found in the literature. He had also already correctly suggested that the apparent differences between the terpenes occurring in various plants would, in large measure, be traced to their optical isomerism. These results of Tilden were known in 1877, but he had not developed their relations any further experimentally. As with so many important advances in the history of science, despite his breadth of vision and energy, a single man was unable to pursue a correct idea to the end and persevere with the correct method of work. Tilden's next step was a backward one in the determination of the constitution of the terpenes, for in 1878 he assumed all terpenes to be of aliphatic structure and to differ from one another only in the position of the double bond. For example, he ascribed to pinene the formula (III), which is given side by side with the formula (IV) proposed in the same year by Armstrong. These formulæ serve to show still further the oscillating ideas of that time. The ideas underlying many of the formulæ proposed during this period were partly correct, *e.g.*, Armstrong's formula for pinene.

(III.)





(IV.)

On the early history of terpene chemistry, Wallach commented in the following terms in a lecture which he delivered before the German Chemical Society in 1891: " . . . if one casts a glance over the old literature of the terpenes, it does not appear a particularly enticing subject for investigation. There were isolated observations in almost incomprehensible abundance. The textbooks listed a large number of terpenes which were designated by special names according to their origin and were held to be really different from one another in virtue of their physical properties. As is to be seen from the literature, it may be that some of the investigators who had carried out extensive researches in this field of work had formed correct and definite ideas about the relations between the terpenes. Real clarity had been reached on no point. To introduce clearness into this widely branched and tangled subject, it was necessary to strive for the following:

" (1) All terpenes that are really different from one another must be sharply and definitely characterised by their properties so that recognition and distinction of the chemical individuals might be possible without difficulty.

" (2) The behaviour and the mutual relations of the individual hydrocarbons must be explicable on the basis of such an exact characterisation.

" (3) Only after the fulfilment of both of these preliminary conditions would it be possible to investigate successfully the individual compounds with regard to their constitution."

The first step in the diagnosis of the terpenes had been taken by Wallach before 1887. For this purpose he let several simple reagents act on the separate fractions of natural terpene mixtures, and investigated whether crystalline reaction products were thus formed. Some of these reagents, such as hydrogen chloride, bromide, and iodide, nitrosyl chloride, and nitrogen trioxide, had been successfully applied earlier in isolated cases; others, such as bromine and nitrogen peroxide, Wallach used for the first time.

Time-saving devices for the preparation of terpene derivatives were introduced by Wallach: Tilden's gaseous nitrosyl chloride was replaced by acetic acid, ethyl nitrite, and concentrated hydrochloric acid; the addition of hydrogen halide was found to be an almost instantaneous reaction in acetic acid solution; the addition of bromine to an ordinary mixture of terpenes usually led to an amorphous mixture of bromides, but by the use of certain solvents, such as alcohol or acetic acid, the crystalline tetrabromides were precipitated, the amorphous products remaining in solution. These are only trifles, but taken together they were of essential importance for the success of the work undertaken by Wallach.

With respect to the mechanism of the formation of some addition products various interesting observations were made. Before this time it was very incompletely understood how far the addition of hydrogen halide takes place with rearrangement. Wallach observed that the so-called pinene hydrochloride (in reality, bornyl chloride) is formed only in an anhydrous medium. Not until some thirty years later did Aschan show that the veritable liquid pinene hydrochloride is formed below $-10°$, and that above this temperature it undergoes spontaneous rearrangement into bornyl chloride. Like pinene, in the absence of moisture limonene and dipentene also add only one molecule of hydrogen halide, but on the other hand, in all these cases, moist hydrogen halide leads to the formation of dipentene dihydrohalide. With respect to the previously mentioned addition of nitrogen derivatives, it was determined that usually a nitroso-group adds to one carbon atom of the double bond and the remainder of the addendum to the other carbon; thus, $NO\cdots Cl$, $NO\cdots ONO_2$, etc. It was observed that by the action of certain organic bases on the nitrosochlorides and the nitrosates, the anion radical, Cl or $ONO_2$, is readily replaced by a nitrogen-containing radical. The original bimolecular addition product is thus transformed into the unimolecular nitrolamine, containing added NO and NHR, which, in contrast to the initial products, usually showed a greater tendency to crystallise.

The important result of three years of work, during which Wallach proved to be a real " busy bee," made possible the listing of eight terpenes which obviously differed from one another, each of which was characterised without ambiguity, in such a fashion that anyone following Wallach's directions could again recognise it. These eight individuals were pinene, camphene, limonene, dipentene, sylvestrene, terpinolene, terpinene, and phellandrene.

Terpinolene was discovered by Wallach and terpinene had not previously been distinguished from other terpenes.

Naturally, this classification was not final. It soon appeared that dipentene was nothing other than *dl*-limonene and should be omitted from the list. Pinene, terpinene, and phellandrene were recognised as mixtures of an α- and a β-compound. Forty years later it turned out that sylvestrene does not occur in nature, for Rao and Simonsen showed that the sylvestrene dihydrochloride used for its isolation is formed from carene present in the ethereal oil. Finally, it may be mentioned that the number of terpenes later recognised as well-characterised individuals, which occur less often in nature or which are artificially available, was increased by Wallach and others. Among the well-characterisable hydrocarbons we mention here only sabinene, the fenchenes, and the carenes.

Naturally, Wallach also included the oxygenated terpene derivatives in his investigations. Indeed, it is the oxide cineole which formed the subject of his first publication in this field. Moreover, during the first few years, terpin and α-terpineol were particularly zealously investigated. They afforded a great incentive to research because of their close genetic relationship to the most important of the terpenes, pinene.

Wallach also extended his researches to the sesquiterpenes, particularly the two most widely distributed members, cadinene and caryophyllene. He soon abandoned work in this field, however, since his technique, which was so valuable for the terpenes, was insufficient for a more profound penetration into the systematisation and elucidation of the constitution of the sesquiterpenes. Wallach possessed the possibilities of only a single investigator and was opposed by the profuse multiplicity of nature. This he realised full well, and clothed the thought in the following expression, so typical of him: "The investigation of the ethereal oils, of both the new and the known constituents, by one single man can embrace only an exceedingly modest territory in proportion to the inexhaustible material which the plant world affords us."

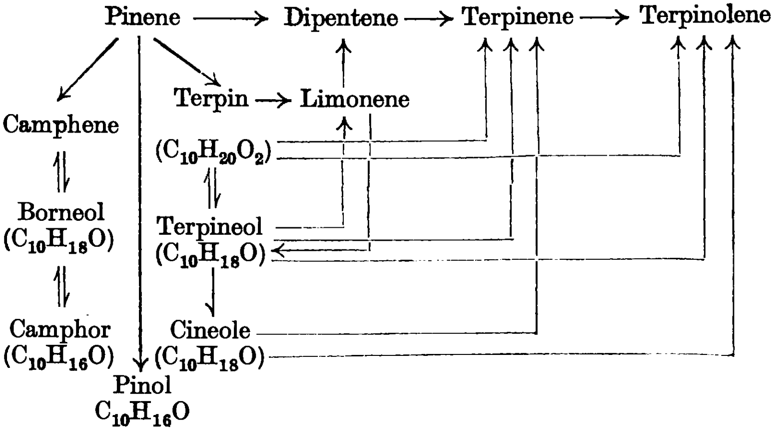
Let us now turn to the second point of Wallach's programme. His fine instinct for the best line of research to be pursued is shown by the fact that, after characterising the individual terpenes, he considered the elucidation of their innumerable mutual relations of greater importance than the determination of their constitution. Long before Wallach, investigators who had dealt extensively with the subject had felt that many reactions in the terpene series are linked with rearrangement of the carbon skeleton. We need mention only Berthelot's conjecture that the transformation of pinene into camphene by passage through bornyl chloride is linked with a double change in the carbon skeleton. Before Wallach, however, chemists had not gone beyond surmises on this question. Wallach therefore proceeded to investigate the cause, conditions, and direction of isomerisation by an examination of the greatest possible amount of material. His more exact researches dealing with reactions employed for the characterisation of individual terpenes had already thrown light on these complex questions, as, for example, in the case already described of the action of hydrogen chloride on pinene, whereby a labile bond in a ring is broken. In most other cases the cause of isomerisation lay in a simple displacement of a carbon double bond. Wallach early recognised that the formulæ of the various possible dihydrocymenes should be considered for the individual monocyclic terpenes. In 1887 he attributed the following formula to pinene :

Far-reaching researches, then, soon showed that the isomerisation of terpenes takes place under the influence of strong acids or high temperature (some 200° and more), while alkalis in general are without influence, save when a double bond can wander in the neighbourhood of a carbonyl group.

The determination of the direction of isomerisation was closely related to partial clarification of the constitutions of the products concerned. To-day, the course of isomerisation is still far from being elucidated in all the cases investigated. The reason for this is that an equilibrium is often established during isomerisation, and we are unable to carry out an exact estimation of the individual components of the equilibrium mixture so formed. In the majority of cases, however, it has been possible to determine correctly the principal course of isomerisation.

A double bond in the ring between two CH-groups wanders by preference into the position $-CH{=}C(CH_3)-$. Double bonds outside the ring wander into it, especially easily those directly attached to the ring itself, the so-called semicyclic double bonds. In the majority of cases, acid reagents proved to be distinctly more powerful instigators of wandering than elevated temperature.

In the collection of his work dealing with terpenes and camphor, published in 1909, Wallach assembled fourteen pages of tables of the most important transpositions which he had carried out with the most varied representatives of the terpene compounds. As an example, we shall quote here only the historically important table of those transpositions of pinene known at the time of its publication in 1891.

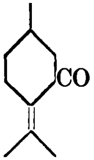


In 1884 Wallach had plunged into work in a neglected garden so overrun with weeds that the useful plants could not thrive. Many good gardeners had already attempted to improve its condition, but each had soon damaged his hands and the weeds had begun to flourish again with renewed vigour. Ought we to reproach Wallach that, in his cleaning and ordering of the garden, he did not rely exclusively on the tools which he had brought with him, but also used those left lying there by his predecessors, if they still appeared serviceable for accomplishing his ends? To be sure, it was often necessary for him to make a fundamental repair in these corroded tools, or to use them in other ways than his predecessors had done. After about the beginning of 1890, the garden was well weeded and it soon enticed other gardeners to investigate the conditions of life and the properties of the plants, and to determine their species. Among them there were many old gardeners who knew from experience how bad the conditions in the uncultivated garden had been. There were also many new workers who, untroubled by the former times, delighted in the new order. They all owed gratitude to the chief gardener whose activity had opened to them a field in which they might work for many years.

First of all should be mentioned Tiemann and Semmler in Germany and Barbier and Bouveault in France, who took over a portion of terpene chemistry for the investigation of which Wallach had not found time, namely, the aliphatic series. Among those working with the cyclic compounds, v. Baeyer, Bredt, and Wagner should be especially mentioned. It is impossible to consider all of this work thoroughly in a short lecture. All that can be done is to point out cursorily its principal foundations. We shall therefore sketch very rapidly its further development, considering only a few selected examples of the last steps leading to the final results.

In the formulæ for the terpenes presented up to the year 1891 we find the side chain containing three atoms of carbon written as $C_3H_7$. The question whether this might be a *n*- or an *iso*-propyl group depended strictly on the constitution of *p*-cymene, since the chemist was not sufficiently advanced with the analysis of any single terpene to be able to decide the nature of the side chain on the basis of the results of degradation reactions. Owing to a series of errors and false assumptions one was inclined to the view that *p*-cymene contained a *n*-propyl group, until in 1891 Widmann cleared up the errors and conclusively established the presence of an *iso*propyl group in this compound. Hence the first possibility was afforded of attacking the complete clarification of the constitution of the terpenes. In 1887 Wallach had already considered the possibility that the terpenes might be built up from isoprene nuclei. He was not entirely convinced, however, of the general correctness of this hypothesis, for in the same paper he discussed the possibility of the existence of terpenes with a *n*-propylene group. Before 1887 the composition of no single compound of the terpene series from isoprene residues had been determined. It is true that Bouchardat had observed in 1875 that dipentene is formed by the polymerisation of isoprene. Apart from this case, in which it was not possible to be certain of the purity of the isoprene used, Wallach first succeeded in proving the identity of dipentene with *dl*-limonene in 1888.

Thus the carbon skeleton of those terpenes and their derivatives which could be transformed into *p*-cymene was determined. Thereafter determinations of the exact formulæ followed in rapid succession. First came the pulegone and menthol groups. Beckett and Wright had carried out the transformation of menthol into *p*-cymene in 1876, and in 1891 Beckmann and Pleissner succeeded in reducing pulegone to menthol by sodium and alcohol. When, in 1892, Semmler obtained β-methyladipic acid and acetone by oxidation of pulegone, he was able to propose the following formulæ for menthol (VI) and pulegone (V) with a very great degree of probability. Their accuracy has been proved by all subsequent researches.



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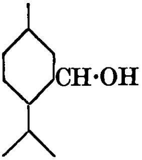

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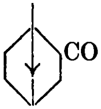
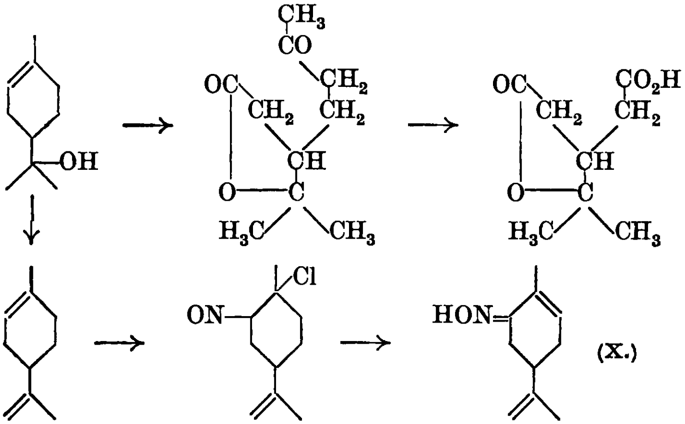


(VII.)

In 1893 followed the establishment by Bredt of the correct formula for camphor (VII), it having been preceded by more than thirty incorrect formulæ proposed by earlier workers.

The clarification of the structures of pulegone, menthol, and camphor was only a single case. The real harvest from the persistent work of Wallach was reaped in 1895, when, with a single stroke, the structure of an entire series of terpene compounds was elucidated. It followed as a result of Wallach's principle, already mentioned, of establishing clearly the relations existing between the greatest possible number of compounds of the terpene series by clarifying their reciprocal rearrangements into one another. Each success with one member of such a group had, automatically, to affect the others. The centre of this series was α-terpineol, for which the following formula (VIII) was demonstrated simultaneously by Wallach, and Tiemann and Semmler.



(VIII.)

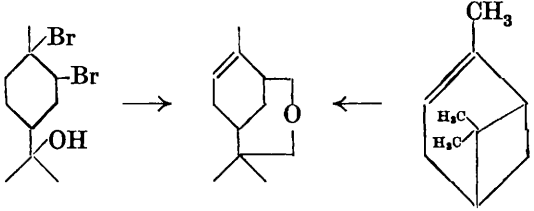
(IX.)

(X.)

This formula had already been proposed by Wagner in the preceding year. Oxidation of α-terpineol with potassium permanganate yields a keto-lactone which, by further oxidation, is transformed into acetic acid and terpenylic acid. The latter was reduced by Schryver to β-*iso*propylglutaric acid by means of hydrogen iodide. Since dehydration of α-terpineol by potassium hydrogen sulphate gives dipentene, the Wagner formula for limonene (IX) received further support. The transformation of limonene and α-terpineol into carvone by various methods led to the clarification of the structure of this ketone. Of these transformations we may mention here the preparation by Tilden and Shenstone of nitrosolimonene, whose identity with carvoxime (X) was proved in 1885 by Goldschmidt and Züner.

The determination of the structure of α-terpineol led to the clarification of the constitution of other genetically related compounds. Of these, only pinene need be mentioned. By treatment of α-terpineol bromide (XI) with silver hydroxide, pinol was formed, besides other products. Wallach also found pinol as a by-product in the preparation of pinene nitrosochloride :

(XI.)



(XII.)

Pinol. α-Pinene.

The observations of Wallach led Wagner in 1894 to propose the formula for α-pinene (XII) which imitated the Bredt camphor formula. This proposed formula was verified by later research. The characteristic development during the years 1893—95 was the realisation that the *iso*propyl group, formerly assumed unsubstituted in all terpenes, usually bore either a double bond or a hydroxyl group, or in some cases, as pinene and camphor, was joined to the ring by a second linkage. In 1894 this formula for pinene was still by no means definitely determined, and Wagner himself modified it again in the following year. In 1896 evidence was again contributed by Baeyer to the accuracy of Wagner's formula of 1894 by the degradation of pinene to pinonic acid, and further, to pinic acid. This formula was accepted by Wallach as the best expression for the reactions of pinene, although he remarked : " This formula is not yet entirely satisfactory . . . namely, the formation of pinol hydrate by oxidation of pinene with oxygen is not at all clear."

Pinene is one of those compounds whose properties are not completely expressed by our customary method of formulation. With this terpene it is necessary to conclude, in the words of Wallach, that " The habit not only of speaking of the bonds between atoms in a molecule, but also of expressing these ideas by constructing rigid models, will certainly some day be considered a stage in the development of chemical theory which has been overcome. On the other hand, exact and reliable experimental determinations will always retain their value."

Arguing on the grounds of historical truth, on this occasion Wallach refuted the "lapidific statements, frequently found in newer work, that the constitution of this or that compound of the terpene series has been determined by this or that chemist." "I believe one may say that, for none of the substances under consideration, what to-day is assumed to be correct with regard to its structure has been ascertained at a single blow." "The proposition of a formula has significance, above all, as a hypothesis helpful to experimental research. Whether a man publicly proposes his working hypothesis or not is entirely a matter of temperament." "Naturally it may happen that among the formulæ proposed—easy, indeed, to design on paper—the 'correct' one exists. If a formula, however, suggests no new idea, its mere proposal must be less valuable than work leading to the recognition that it is really tenable."

Wallach was in fact not the quickest in the race for the proposal of correct constitutional formulæ, nor indeed could he be, because of his character. Those which he proposed at first were particularly for the purpose of orientation. After having suggested them, he sometimes neglected to propose modifications which might be more nearly in accord with the results of later experimental investigation, and the formulæ were often developed by others. The majority of these correct formulæ he may himself have considered, but as critical sovereign connoisseur of the subject and all its difficulties he perceived possible objections which made him hesitate to advance their publication first. Often, however, it was he himself who offered the final experimental proof of such formulæ proposed by others, and he hesitated to accept a formula before it had been really proved.

About the year 1895 the heroic times in terpene chemistry ended and Wallach ceased to play the rôle of the pioneer. We can, in large part, pass over his later work and merely point out briefly a few of its more striking features. These should include the two investigations dealing with various dicyclic representatives of the terpene series and with simple alicyclic compounds. It is obvious that Wallach's extensive occupation with the terpenes must soon have led him to turn his attention to their simple analogues.

Wallach used experiments with the simple alicyclic five- and six-membered rings as models for his researches on their complicated analogues of the terpene series; in particular, for the study of isomerisation reactions involving shifting of the double bond or rearrangement of the ring.

Among Wallach's newly begun later researches in the terpene series, those with thujone and fenchone may be mentioned. His work on thujone ran parallel with that of Semmler on tanacetone, which two compounds, in the course of the researches, were recognised as optical isomerides. In both cases, Wallach again proved to be the cautious experimenter who left the proposal of the correct formulæ for thujone and fenchone to the younger and more enterprising Semmler.

In the conviction that enough material for the justification of the old formulæ had not been advanced, Wallach remained constantly occupied with his old researches until his final years. He had begun as a busy bee; as such he ended.

Wallach's work found recognition everywhere. In 1889 he was called to Göttingen as successor to Victor Meyer. There he retained the direction of the Chemical Institute until 1915. During the entire time, he lived near the laboratory in the old home of Friedrich Wöhler. As a rare exception among the great German chemists, Wallach remained a bachelor.

In foreign countries Wallach received more special recognition by his English colleagues. In 1908 he was elected Honorary Fellow of the Chemical Society, and in 1909, Honorary Doctor of the University of Manchester. His native country did not lag behind in paying him honour: he became Honorary Doctor of the University of Leipzig and of the Technological Institute of Braunschweig and in 1912 the Verein Deutscher Chemiker also nominated him to honorary membership, and the Deutsche Chemische Gesellschaft to its presidency. As pioneer, *par excellence*, in organic chemistry, Wallach was awarded the Nobel Prize in 1910.

Was Wallach a genius? With regard to this query, recently raised, I believe that we can comprehend Wallach's personality better by studying his place in the history, not only of the terpenes, but of organic chemistry in general, than by trying to find a label which may be glued to him. Picture organic chemistry with Wallach's work removed—what a gap is left! When I say this, I think not only of his results in the field of the terpenes but also of his method of attack. He approached his problems, not with brilliant theoretical speculation, but only with an extremely sensitive recognition of the correct lines of work and of their technique, and followed with severe perseverance those paths which alone could lead to the goal. Wallach's highest ideal was not theory, not the formula, but carefully and reliably performed experiment. In this respect, he resembled his two great compatriots, Emil Fischer and Adolf von Baeyer. He differed, however, in one essential point from them. While they accomplished much by the synthesis of natural compounds as well as by their analysis, Wallach was primarily the analyst. If, to use his own words, the methods of analysis in organic chemistry have reached so high a degree of perfection that it " has become possible to follow an analytical procedure therein with the same degree of certainty as the search for the elements in an inorganic substance," it is to a great extent a service rendered by Wallach.

We can conclude our review of the life work of Wallach in no more fitting way than by recalling the man who was in many respects the complement of Wallach in the history of the chemistry of the terpenes, as well as of organic chemistry in general, namely, the great synthesist William Henry Perkin, founder and unrivalled master of alicyclic synthesis, to whom, by the artificial preparation of α-terpineol and dipentene, it was particularly assigned to give the final crowning glory to the work of Wallach.