OBITUARY NOTICES.

JAMES BELL.

1899—1941.

JAMES BELL, Sc.D., M.D., Fellow of Trinity College, Dublin, died at the height of his powers on January 23rd, 1941, after an illness contracted while on service with the Irish Army.

Born 42 years ago in Belfast, he was the son of a remarkable father, who, in the leisure hours permitted by hard work in the Belfast shipyards, became one of the foremost geologists in the British Isles. James Bell received his early education at the Royal Academical Institution, Belfast, and entered Trinity College, Dublin, in 1916. There he graduated with high distinction in Experimental Science and Mathematics in 1920, and served as Demonstrator and Lecturer in the Department of Chemistry of his own University for seven years. In 1927 he was appointed to a Lectureship in Biophysics.

Although this appointment involved the transfer of most of his activities to the Department of Physiology, he continued to be keenly interested in Chemistry, and lectured to the end of his career on aspects of Physical Chemistry related to Physiology.

Bell published a number of communications dealing with guanidine and dicyanodiamide in this Journal, but his later research work dealt mainly with medical subjects, such as the hydrodynamics of the circulation in relation to arterial disease.

In 1935 Bell was elected a Fellow and Tutor of Trinity College, and for a short five years held a position of especial importance and usefulness. Never was there a more popular, more efficient, more critical, or kinder Tutor. The students who came under his influence will remember him with gratitude to the end of their days, for their interests were his chief concern, and he cheerfully sacrificed his comfort and convenience, and perhaps his health, to serve them. He was brought into contact with large numbers of students in another way also, for he played an important part in the formation of a Volunteer *Sluagh* (the equivalent of an O.T.C.) in the College, and was himself the first Volunteer of a University *Sluagh* to receive a Commission in the Irish Army.

To the writer, and many of his other colleagues, Bell was a tower of strength. To him one never turned in vain for advice or help, nor did he ever make a promise which he did not most faithfully fulfil.

He took a deep interest in the Student Christian Movement, filling for many years the office of President of the Dublin University branch of the S.C.M., and played a leading part in the work of the Presbyterian Church in Dublin.

He was very interested in the Institute of Chemistry, of which he was a Fellow, and was Honorary Treasurer of the Dublin Section from 1928 to 1940.

He became a Fellow of the Chemical Society in 1922.

KENNETH C. BAILEY.

SIR GILBERT MORGAN.

1870—1940.

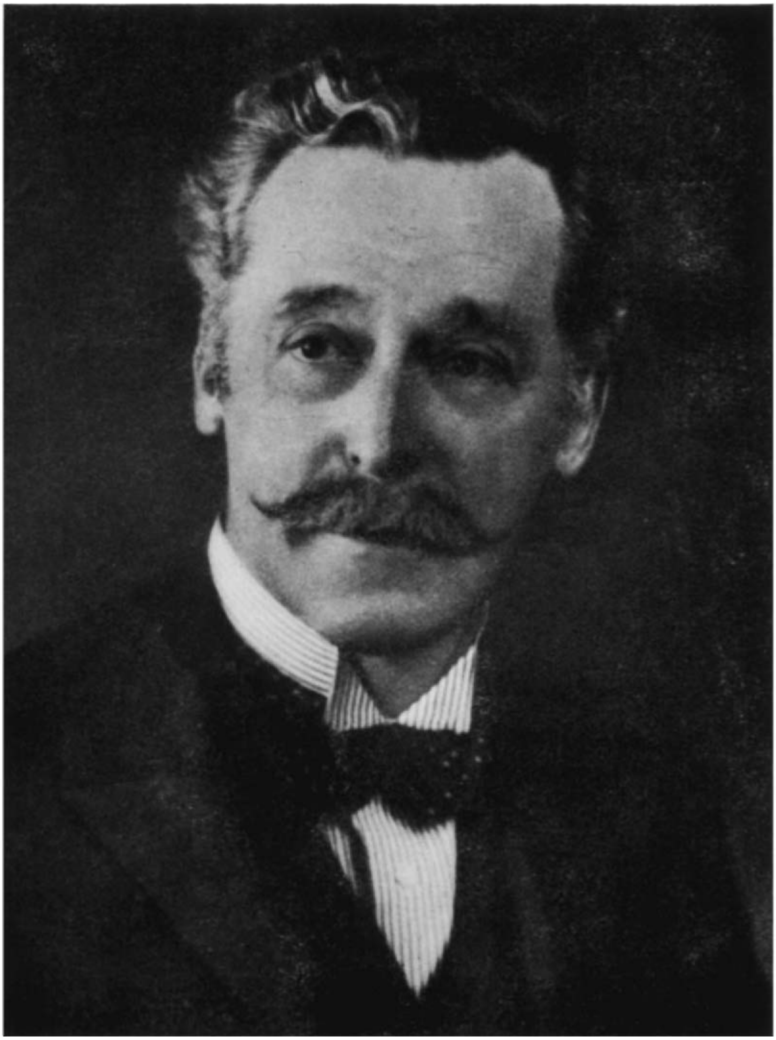
THE death of Sir Gilbert Morgan at Richmond on February 1st, 1940, has removed from our Science a remarkable personality. "Life achieves its summit when it does to the uttermost that which it was equipped to do." In his chosen line Sir Gilbert reached the highest point attainable. He lived to the full the life he wished to live and served without deviation the standards which he set before himself.

Gilbert Thomas Morgan was born on October 20th, 1870, his father being Welsh and his mother French-Swiss. His early years were spent at Essendon in Hertfordshire and here was fostered an appreciation of country things which he retained throughout his life. He was never ashamed of the filial and family pieties that our Time tends to disparage and weaken. In later years, in spite of the great and increasing demands made upon him, he visited with regularity his aged and blind father who still resided at Essendon and from whom he undoubtedly derived a full measure of characteristic Celtic enthusiasm and imagination.

Morgan was educated at the Central Foundation School, Cowper Street, in the City of London, and in 1886 entered the Finsbury Technical College, which had been established in 1878 by the City and Guilds of London to teach science with a practical bias. The training which Morgan received here during the formative years profoundly influenced his scientific outlook. It could not be otherwise. At Finsbury at that time was the somewhat shy and versatile Professor—Raphael Meldola, who was assisted by that gifted teacher of organic chemistry, Frederick William Streatfeild and by J. Castell-Evans—a striking figure and personality—responsible for the teaching of inorganic chemistry. How well these men moulded the splendid material which came into their hands is reflected in the careers of the many distinguished Finsbury men. A very important factor in the success of the Finsbury training was not only the kind of instruction given but the early emphasis laid upon the practical applications of much of the work done. This made an abiding impression on Morgan, who always had a pronounced sense of practical values. Further, as the Finsbury training engendered self-reliance and evoked a spirit of enquiry and enterprise, the environment must have been particularly congenial to a student of Morgan's calibre. The great interest which Morgan always displayed in the rare earths goes back to this period, for under the guidance of Castell-Evans he spent an Easter vacation isolating ceria from the mineral cerite. He records that " this practical exercise imbued me with an attraction for the rare earths which I was able to cultivate further in later years." His first introduction to research took place at Finsbury in the private laboratory of Professor R. Meldola, F.R.S., and one of the topics they studied was the action of concentrated nitric acid on azonaphthols and their ethyl derivatives. They found that the concentrated acid ruptured the azo-linking, regenerating the diazonium salt; the naphthol residue became nitrated. This work was carried out in 1889. In 1905 a German chemist, O. Schmidt, took up this nitric acid treatment of azo-compounds and developed a process for diagnosing azo-dyes which is sometimes known as Schmidt's method.

At the end of his College career Morgan secured a post under Mr. Robert Holliday, the youngest son of Read Holliday, the founder of the well-known firm of colour-makers at Huddersfield. Here he was confronted with problems in both organic and inorganic chemistry, but amongst all the investigations that he undertook, one in particular made an indelible impression. Morgan was deputed to find out whether a new colour-intermediate could be prepared by the condensation of formaldehyde and phenol. A condensation product was obtained, but as it refused to yield dyes it ceased to be of any further interest to his employers. However, it was set aside and gradually solidified to a clear amber resin. Forty-six years later, in an address to the Society of Chemical Industry, Morgan made the very human confession : " I often think of the contents of that bottle which contained the potentialities of fortune, although we did not perceive it at the time." Baekeland's patents, it will be recalled, dated from about 1906. It was during this period at Read Holliday's that Morgan first developed a keen interest in autoclaves and chemical reactions carried out at high pressures. He relates how he borrowed from a colleague a laboratory autoclave in order to hydrolyse α-naphthonitrile with alkali under pressure. The ammonia generated in the process attacked the copper gauge, ultimately perforating it and rendering it useless. After this experience, the study of autoclaves seemed worth while.

In 1894 Morgan took a bold decision. He decided, with some reluctance, to give up his industrial career and resume his scientific studies. With this end in view he secured a Royal Scholarship and entered the Royal College of Science, London, where he was destined to spend many happy and successful years first as student, later as demonstrator, lecturer and finally assistant-professor. In view of his exceptional chemical attainments he did not follow the usual course of study but was soon assisting Professor William A. Tilden, F.R.S., with various research projects. In 1896 he graduated B.Sc. (London) with first-class honours in chemistry and gained the Frank Hatton Prize of the College, where he continued as a demonstrator and research worker. Morgan now began with



G. T. Morgan.

[*To face p. 690.*

characteristic energy and success a programme of research work which during the ensuing years covered such a wide field. His first step was to resume certain investigations which had aroused his interest at Read Holliday's, *viz.*, condensation of aldehydes and aromatic amines and studies of aromatic compounds containing nitrogen. In conjunction with several co-workers, especially Miss F. M. G. Micklethwait, he published a series of papers, several of which dealt with diazonium compounds and non-aromatic diazonium salts. Morgan's interest was also aroused at this period by the residual affinity of coumarin in forming salts with inorganic acids and further by the organic derivatives of phosphorus, arsenic, and antimony. Incidentally some of the work on organic antimonials, at a later date, proved to be of interest to the Chemical Warfare Committee.

It is important to emphasise that Morgan's zeal for research never interfered with the conscientious discharge of a most congenial duty—the teaching of his students. Morgan enjoyed lecturing and took the greatest care in the preparation of his lectures. He spoke with easy, natural fluency, and the encyclopædic range of his knowledge in both inorganic and organic chemistry made his teaching both thorough and stimulating. He had a firm belief in the value of numerous and even elaborate lecture experiments. Nothing gave him greater pleasure than to see on his lecture table a display of beautiful specimens and to be able to illustrate his lecture by some particularly striking experiments.

During his association with the Royal College, Morgan was a very keen supporter of the Students' Chemical Society, at which senior students and others contributed scientific papers. He considered that participation in such activities was a most valuable part of the training of a chemist.

This important period in Morgan's career terminated in 1912 when he took up a Professorship in the Faculty of Applied Chemistry in the Royal College of Science for Ireland. He retained this appointment till 1915 and after a short time at British Dyestuffs Ltd. succeeded his former teacher, Meldola, as Professor of Chemistry at Finsbury Technical College, where he remained till 1919. During the war years his publications were necessarily restricted, as he was engaged on work of national importance. His advice meanwhile was at the disposal of others and those associated with him during the years of the Great War have recorded their gratitude to him for his ever ready help and wise counsel.

In 1919 Morgan became Mason Professor of Chemistry in the University of Birmingham in succession to Professor P. F. Frankland, F.R.S. Morgan recalled with particular pleasure that his old teacher, Professor Sir William A. Tilden, had held the Chair of Chemistry in the Mason College, Birmingham, from 1880 to 1894 before he took up his Professorship at the Royal College of Science, London. The new professor entered on his duties with his usual enthusiasm and attacked with relish the many problems confronting him. His first task was to re-equip the chemical laboratories. During the Great War the recently-built laboratories at Edgbaston had passed into the hands of the Army Medical Services and had been more or less devastated by their military occupants. In August, 1919, these modern laboratories again became available for University purposes, and thanks to the energy of the professor and his staff were ready to receive students at the beginning of the session. The University authorities at this time had adopted the bold policy of accepting ex-Service students from all parts of the country, with the result that every department was crowded with undergraduates far in excess of the annual entry of pre-war years. Morgan fully recognised that the duty of instructing these new students, many with meritorious war records, constituted a first call on the time and energies of the teaching staff. He did not forget, however, that " the true purpose of a University is to communicate to the minds of the young generation not only science in the state of completeness but also science in the state of growth," and to this end the provision of research facilities was vital. Research had always played an outstanding rôle in the activities of the Department of Chemistry at Birmingham, and Morgan determined that during his Directorship this tradition should be fully maintained. Although the teaching demands were heavy and engrossing, there was a spirit of renascence in the air and very soon original investigations were proceeding in all the overcrowded laboratories, side by side with more elementary studies. The initiation of an active research school was made possible by two groups of research workers who had accompanied Morgan from Finsbury and constituted the nucleus of his research team. One of these groups was maintained by the British Dyestuffs Corporation, the directorship of which at that time kept research colonies of chemists-in-training at University centres. These post-graduate students, who were engaged on the study of coal-tar intermediates and synthetic dyes, were valuable auxiliaries in the work of restoration of research activities. The other research group was made possible by the generosity of the Department of Scientific and Industrial Research, which had been formed during the Great War by the Government to make good the deplorable deficiency in our national facilities for fundamental investigations in pure and applied science. Out of this co-operation with the D.S.I.R. came the noteworthy researches on chelate co-ordination compounds carried out in collaboration with Dr. J. D. Main-Smith, and the important investigations on organic derivatives of selenium and tellurium in which Morgan had the assistance of Dr. H. D. K. Drew. At this period Morgan devoted considerable attention to an experimental study of Werner's co-ordination theory of valency and chemical constitution.

In a comparatively short time Morgan had established a vigorous research school and he was enjoying to the full his teaching and his contacts with chemists in the Midland Area. He had gained in full measure the respect and affection of his staff by the confidence he freely reposed in them and by the freedom with which he invited and received their suggestions. Staff and students alike felt that to have worked with him was an experience to which they would always look back with gratitude. It was therefore with very mixed feelings that those associated with him at Birmingham learned that he had resigned his Chair in 1925 and had been appointed Superintendent of the new Chemical Research Laboratory of the Department of Scientific and Industrial Research. So began what Morgan himself described as a State experiment in Chemical Research and was destined to be the crown of his scientific career. He was admirably fitted for this important post by his manifold chemical interests, his great energy and his ripe administrative experience.

The origin of the Chemical Research Laboratory is interesting. The work of the D.S.I.R. began in 1915, and during the next ten years the Department had become associated with certain chemical investigations which were carried out by groups of workers frequently located in widely separated laboratories. It was decided that some economy and increased efficiency could be realised by concentrating these research activities in a centralised laboratory. In furtherance of this idea a suitable site was chosen on the Bushey Park Estate near the National Physical Laboratory, and in 1924 the building of the Chemical Research Laboratory began. The duty of advising the D.S.I.R. as to the programme of work to be undertaken was delegated to a Chemistry Research Board, which also exercised general supervision over its execution. At the outset executive control was vested in Sir Richard Threlfall, F.R.S., as a part-time Director of Research, and Morgan as whole-time Superintendent, but from 1927 onwards this responsibility devolved on Morgan as whole-time Director of Research. The fascinating story of this great venture was told by Morgan in the address he gave to the British Association at Bristol in 1930, when he was President of Section B. In this address he emphasised that a valuable function of the Chemical Research Laboratory is to provide competent and enterprising investigators with favourable opportunities for developing their inventive talent in work of national importance. That the laboratory fully discharged this function during Morgan's directorship is clear from the variety and range of researches which were undertaken. Investigations prosecuted with signal success included work on synthetic resins, low-temperature tar, high-pressure reactions, corrosion of metals, chemotherapy and water-pollution. In addition, a limited amount of research in pure chemistry was always in progress, and here again the results obtained were of great value. No one privileged to pay a visit to this research centre will forget the obvious pleasure it gave to the Director to act as guide and to outline, with characteristic enthusiasm, the various researches which were in progress. Morgan was justly proud of the Chemical Research Laboratory and visitors left it with a feeling of profound admiration for what had been achieved. When Morgan resigned his Chair at Birmingham to take up his new post at Teddington, certain doubts lingered in his mind as to the wisdom of his action. In later years he was fully convinced that his decision had been the right one, for he had been given unique opportunities of undertaking investigations which it would have been impossible to embark on in an academic post. No one could have been better fitted for the Directorship of the Research Laboratory at the particular stage of its growth, when it was winning the confidence of chemists and finding its way to public recognition. Now it is an established institution; then it was on its trial. As Director of the Research Laboratory, Morgan found full scope for his generosity of character, his optimism, his courage and his resource. He carried aloft a torch kindled from chemists of a great past. If others have kindled it from him and sustain it for the next generation, that service alone will entitle him to a high place amongst his contemporaries. When Morgan retired in 1938, this laboratory had won an important place amongst our national scientific institutions and for this fine achievement Morgan was primarily responsible. He was too active to contemplate retirement and he accepted an invitation to become Chairman of the Research Fund Committee of the Institute of Brewing. The Institute was very fortunate in securing his services. He entered upon his new duties with customary zeal and soon identified himself with this great industry by seeking the society of brewers, maltsters, hop-growers and others interested in brewing research. His primary task was to determine the relative importance of the different branches of the Research Scheme of the Institute of Brewing, to assess the value of the work already done, and to mould future policy so that the maximum benefit might accrue to the brewing industry. His ideas on these matters were outlined in an address which was published in the *Journal* of the Institute of Brewing after his death, and one realises the valuable results which would have been obtained for the brewing industry if he had been spared to carry on his work.

Morgan brought many useful weapons to the battle of life—a singularly retentive memory, keen appreciation of the point at issue, considerable powers of organisation, and love of work. Yet to the many who knew him and admired him as a chemist and loved him as a man, the characteristic that was perhaps outstanding was his tireless energy. It was almost impossible to imagine Morgan as really idle. Above all, the impression always remains of an immensely industrious being who never spared himself. At the Royal College of Science after a day's teaching he would continue with his research work till the small hours of the morning, and at Birmingham and Teddington his working day was always a very long one. He was never bored or at a loss for an occupation and his well-stocked mind and phenomenal memory made his conversation stimulating and worthy of recollection. He was intensely interested in his fellow-men and much could be written of his clubbable qualities—his gift of friendship, his gaiety, his enjoyment of hospitality. A good companion indeed of whom every memory amongst his friends must always be happy and affectionate. Yet he was a reticent person. A trivial fact shows this. An old friend, on close terms of intimacy for many years, was never informed by Morgan of his marriage. Amongst his finest attributes were his warmth of heart and ready sympathy. In a letter to *The Times* after his death a correspondent revealed that Morgan had made himself responsible for the cost of insulin treatment for one of his less fortunate neighbours at Essendon. Always the most approachable of men, he retained to the end that youthful gaiety of spirit which endeared him alike to young and old. He was always particularly happy in the company of young people. Many of his former students at Birmingham will recall with what regularity and keenness he attended the weekly dancing class held by his research and senior students. He was always deeply concerned for the welfare of his students, and this found expression in a letter which he sent to the Press in 1924 at a time of serious trade depression. It is a characteristic and revealing contribution.

" To the Editor of the ' Birmingham Post.'

" Sir, The ample news-sheets of the ' Post ' are to-day swollen to an extraordinary extent, like a river in full spate, by the inclusion of the degree lists of Birmingham University. Those of us who have had the training of these graduates, who know them personally, and have some parental solicitude for their future careers, regard these lengthy lists with mixed feelings, realising that the next essential step is the employment of all this scholarship and scientific training in the service of the community.

" Apart from recommendations to many teaching appointments, I have during the last four years assisted in placing some seventy chemical graduates in industrial posts. The geographical distribution of these positions is, however, curious and intriguing. In the majority of cases these appointments are outside the Birmingham area. A chemical graduate, like the prophet of old, is not without honour save in his own country. Yet it seems to me that many local industries, being largely based on chemical principles, would profit from the co-operation of fresh young minds chemically trained, and many of them sharpened by research experience. Nevertheless, the very existence of these students is seemingly ignored by the local community except during one day in the year, when they force themselves on the attention of the public.

" In this connection I would suggest the following sum in double rule of three to the consideration of Birmingham Rotarians and other influential directors of local industries. If a thousand students playing the fool in a hospital carnival for one day can extract £3,000 from the general public, how much would be earned by one student working seriously at a scientific job for a whole year? The answer will vary somewhat with the complexity of the industry and with the facilities offered, but my general solution of the above sum, based on experience mainly gained in other districts, is that a well-trained young chemist will earn his salary (which is usually not princely at the outset) plus a reasonable profit for his employer.

" The above-mentioned graduates who have gained employment outside the Midlands have presumably given this form of satisfaction, for they retain their jobs. London—that Minotaur of the Thames—has swallowed many of our chemical Erics and Ericas, and hard-headed employers in Lancashire and Yorkshire have given to several others the opportunity of their lives.

" From time to time I am requested to give expert advice to local manufacturers wishing to make a new chemical product or to improve an existing process, but owing to the pressure of multifarious duties I have but little time and energy left to devote to such problems. To these enquirers I would suggest a better and more efficacious way—namely, to enlist the whole time services of a chemical graduate, to give him reasonable facilities for working out the problem, and not to be too disappointed at the slow rate of progress during the first year. The astute directors of one London firm of world-wide reputation have found that a chemical research laboratory staffed almost exclusively with Birmingham graduates saves them annually many thousands of pounds in their contracts for new materials.

" In advocating the claims of our scientific graduates I have restricted my remarks to chemistry as being the only science on which I can write authoritatively, but obviously a similar plea could be made out in regard to the utilisation of students trained in other branches of learning.

G. T. MORGAN, F.R.S.

Chemical Department, The University,
Edgbaston, July 3."

Any account of Morgan's life would be incomplete which does not emphasise his wit and humour. As a companion he was vivacious and ever ready to enjoy a good story. He could always see the humour of a situation but his fun was never malicious. Lecturing on the Periodic Table he could not resist the temptation to tell his students to " think periodically." A very talkative colleague who was proud of the fact that he had none of the common vices was dubbed by Morgan " an inert gas." There is, however, no need to recall such things, for memories of his laughter, wit, and sense of comedy come quick and relentless. He was a " fellow of infinite jest " and his friends will remember with affection his vivid personality.

Morgan was devoted to the Chemical Society and he served it well. He maintained that the Chemical Society merited the support of all members of the profession, for it had played the chief part in spreading chemical knowledge amongst British chemists and in securing general recognition for Chemistry throughout the Empire. He deplored the fact that much that the Society had accomplished in these directions had been undervalued by the rising generation, " who did not realise that with truly maternal instinct the mother-society had placed her resources freely at the disposal of the daughter societies." Throughout his life Morgan was a regular attender at the meetings of the Society and he was particularly gratified if he could take part in some vigorous discussion after the reading of a scientific communication. For some years he was Editor of the Journal, and from 1910—1912 acted as an Honorary Secretary. On several occasions he served as a Vice-President and in 1933 he was elected President. His selection for the Presidency gave him great satisfaction, for he was proud to be included on the roll of distinguished chemists who have held that high office. Other chemical organisations also claimed his interest. In the affairs of the Society of Chemical Industry he took a leading part and was a Past President. He received the Medal of the Society of Chemical Industry in 1939 and on this occasion delivered his address on " Personal Reminiscences of Chemical Research " which concluded with the passage : " This outline of experiments still in progress brings to a close my reminiscences of 50 years of chemical research. . . . It has been a most interesting and engrossing pursuit, not so very long when I now look backward, but rather like a watch in the night. There is still much to be done which I shall never do. But sooner or later a summation must be made and it now seems to me that my part in these enterprises has been mainly catalytic. At times I may have been able to direct such chemical investigations into specific channels, but on the whole much has been left to the goodwill and enterprise of many co-workers to whom I now desire to express my warmest gratitude and thanks."

Morgan's attachment to the Institute of Chemistry began in 1897 when he was elected to the Associateship, one of his examiners being Professor P. F. Frankland, F.R.S., his predecessor in the Chair at Birmingham. He became a Fellow in 1901 and later served as a Vice-President and as a Censor. Morgan took a very keen interest in the scheme for the award of National Certificates in Chemistry conducted under the Joint Committee of the Board of Education and the Institute of Chemistry. He acted as Chief Assessor from the inauguration of the scheme in 1921 until his death and contributed greatly to its success. He was Chairman of the Bureau of Chemical and Physiological Abstracts and during his tenure of that office devoted himself with great success to making these abstracts worthy of British Chemistry. It will be apparent that to few men was the cause of Chemistry nearer the heart than to Morgan. He was ever ready to take over responsible and arduous duties and the spirit in which he worked is an inspiring example. An eminent statesman has said that there is only one form of congratulation in this world worth anything, and that is the expression of good will and the expression from your own peers that you have tried to do your duty. Morgan received this in full measure. As a member of the Council of the Chemical Society he was always ready to make his contribution to its proceedings and he had very definite opinions on matters of policy. He cared passionately for causes, but it cannot be contended that he enjoyed the battle itself. Generally he was the patriotic warrior prepared to go into battle when wanted, but at heart a lover of peace. Actually he was no politician but a bundle of generous enthusiasms.

Morgan gave much thought to the question of how our main chemical associations could effect economies in administration and provide a more comprehensive service of chemical publications. He considered that the co-operation of the three Chartered Bodies—the Chemical Society, the Society of Chemical Industry, and the Institute of Chemistry—if adopted, would represent only a very small advance. In Morgan's view it would be impossible for long to keep the scientific and professional aspects of chemical organisation in water-tight compartments and he affirmed that already the lines of demarcation were becoming obliterated. His solution was a unified Society of Chemistry. However, he appreciated full well that the extent to which one all-embracing society could legislate for both the scientific and the professional needs of chemists was a knotty problem in any comprehensive scheme of reunion.

Over a period of some fifty years Morgan published alone or in collaboration 350 scientific communications. The subjects which he dealt with cover a very wide field, for he chose to disperse his interests rather than to concentrate them in one direction. It was a choice which gave him a scientific life full of variety and perhaps richer in pleasure than a more austere career could have been. Although he was fascinated by applied science, it never weakened his allegiance to pure science. He rightly maintained that applied science would fade and die unless the pursuit of knowledge was honoured in this country as the highest of human aims. To do full justice to the immense contributions which Morgan made to chemistry would require a much lengthier notice than is permissible here. Fortunately Morgan himself has dealt in detail with his chemical investigations in the address: " Personal Reminiscences of Chemical Research," which he delivered before the Society of Chemical Industry on July 11th, 1939. His selection of topics gives some idea of the range and importance of his researches. He discusses autoclaves, high-pressure reactions, chemotherapy, tar research, residual affinity and co-ordination, selenium and tellurium derivatives, non-aromatic diazonium salts and a general reaction in diazo-chemistry. Although his contributions to these various chapters of chemistry are of definite significance, it is perhaps true to say that his name will always be specially associated with advances in the chemistry of co-ordination compounds. He had a profound admiration for the genius of Alfred Werner, and this is readily discernible in the obituary notice which Morgan wrote for the Journal of the Chemical Society. Over many years, in the course of his investigations, Morgan accumulated a wealth of experimental data on co-ordination compounds. The particular value of those data was that they could be used to test the truth of the principles of valency and molecular constitution which were being laid down during the same period. As Sidgwick has very pertinently stated: " A theory of valency can only be justified by showing that it is applicable to chemistry as a whole: it is not enough that isolated examples can be quoted in its defence." Incidentally Morgan introduced the very convenient term " chelate," now so widely used for rings containing co-ordinated links. Amongst the problems which interested Werner was the close analogy between the lakes of mordant dyes and the metallic derivatives of β-diketones and he expounded the view that mordant dyes were internal metallic complexes. After Werner's death, Morgan and Main-Smith began an examination of this idea and, selecting representative dyes, showed that any acidic substance capable of forming a colour lake must contain a chelate group capable of combining co-ordinatively with the metallic mordant. In every case examined the resulting lake proved to be an internal metallic complex. Morgan was always greatly intrigued by the chelate group acetylacetone, which enters into combination with the majority of metallic and metalloidal elements and even with certain non-metals. With H. W. Moss, he prepared and examined scandium acetylacetonate and in collaboration with H. D. K. Drew isolated the acetylacetonates of gallium and germanium. Morgan was very fond of quoting a remark by Sir William Crookes, who, on hearing that scandium acetylacetonate could be distilled without decomposition under reduced pressure, declared that acetylacetone had " given wings to the metals." The contribution which Morgan made to the stereochemistry of co-ordination compounds is a very important one. With F. H. Burstall he resolved 6-covalent nickel and thereby solved an outstanding problem. Again, his work with the polypyridyls as chelate groups has raised new stereochemical problems of great interest. Morgan was always fully alive to the contributions which physics could make to the solution of chemical problems. He was particularly interested in the application of *X*-ray methods to the solution of structural problems in both inorganic and organic chemistry.

In 1923 he published with Sir William Bragg a communication on the structure of that curious compound, basic beryllium acetate, and was associated with Dr. Astbury in a paper on the structure and isotrimorphism of the tervalent metallic acetylacetonates. The so-called rarer elements had a definite fascination for Morgan and he selected as the subject for his Presidential Address to the Chemical Society in 1935 his researches on the rarer elements. In this address Morgan described these researches, carried out in association with H. D. K. Drew, on organic derivatives of selenium and tellurium which resulted in the discovery of several entirely new groups of organo-metalloidal derivatives. One series of these tellurium compounds possessed exceptional germicidal properties in aqueous solution, but unfortunately they were somewhat poisonous and their bactericidal potency was greatly diminished in serum. Here it is worth recording that Morgan found the relationship between chemical structure and bactericidal activity a subject of particular fascination. Morgan's great interest in practical problems is reflected in this Presidential

Address when he discusses the possibility of extracting germanium and gallium from Northumberland coal ash and describes a method for winning rhenium from Australian molybdenite.

Throughout his life Morgan was irresistibly attracted by the chemistry of dyes. Few men had such an intimate knowledge of the history of the dyestuffs industry, and the revival of this industry in the post-war years gave him great satisfaction. He was a member of the Dyestuffs Licensing Committee and in that capacity rendered signal service to the industry. In 1921 he was awarded the Gold Medal of the Worshipful Company of Dyers, of which later he was a liveryman. Morgan joined the Company in 1923 and his seniority would have led to his election on the Court in the near future. To this he was looking forward not only because of his interest in the ancient Charter and Constitution, but also because the Company is very closely associated with the great dyestuffs and dyeing industries.

During a long life of service to chemistry many honours came to Morgan. He was elected F.R.S. in 1915 and received the Honorary Degrees of the Universities of Dublin, Birmingham, and St. Andrews. Amongst many other distinctions, he was a Fellow of the City and Guilds of London Institute, an Honorary Associate of the Manchester College of Technology, and an Honorary Member of the Society of Public Analysts. Morgan was an Associate Member of the Chemical Warfare Committee during 1914—1918, and in January, 1920, was appointed an O.B.E. in recognition of his services. In 1936 he achieved the honour of Knighthood for his services to science and the nation.

Sir Gilbert Morgan started life with few advantages except his natural abilities. It was his natural ability, his industry, and his courage which made him from an early period of life map out a scheme for his life's work. He was the architect of his own fortunes; he made his own friends and he qualified himself for his career by ceaseless study from early years. His scientific interests were exceptionally wide and he proceeded to make himself a master of every subject to which his keen mind was attracted. He was, it is true, exacting towards others, but he was not nearly so exacting towards others as he was towards himself. Morgan was one of that small but enviable band of men who compel other men to love them. And so today his friends think of him with wistful affection, as of one who has carried away with him some of their sunlight. He died as he would have desired, in harness, a harness put on himself in youth and worn triumphantly through a long life.

W. WARDLAW.

SIR WILLIAM J. POPE.

1870—1939.

WILLIAM JACKSON POPE, the eldest of eight children, was born at 89 New North Road, London, on March 31st, 1870. His father, William Pope, was a native of Biggleswade who came to London in 1858, and in 1869 married Alice Hall of Prudhoe, Northumberland. Both parents were staunch and active members of the Wesleyan Methodist Connection and regular attendants at Wesley's Chapel, City Road, of which William Pope was a Trustee for many years. He served also as one of the managers of the Radnor Street Schools attached to the City Road Circuit, and exercised considerable influence in directing its affairs. Serious though without the least austerity, the early home training was undoubtedly a contribution towards the characteristic thoroughness which distinguished Pope in all his scientific work.

In January, 1878, Pope entered the Central Foundation School, where he received a thorough grounding in subjects of great value to him in later life. His ability to learn quickly gave him leisure to pursue particular interests and at the age of 12 he had in his bedroom cupboard a collection of chemicals and simple apparatus with which he made experiments, delightful to the younger members of the family but not always viewed with favour by his seniors either at home or at school. One of the earliest *X*-ray photographs taken in London was of his hands. This showed clearly a misshaped bone due to an unexpected explosion which terminated one of these experiments.

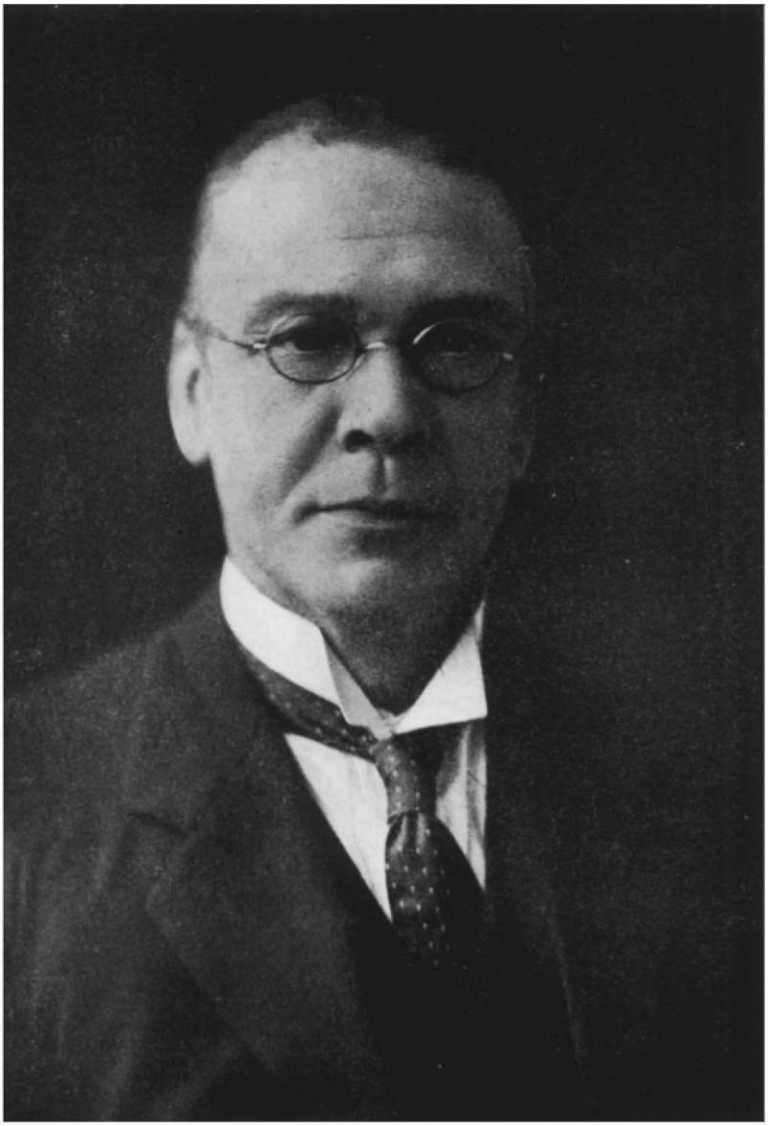
Whilst at school Pope acquired great skill in the practice of photography. At that time the operator had to conduct all the processes of developing and printing, and the fact that a large number of his photographs more than 50 years old are still in perfect condition affords direct evidence of his complete dexterity in his youth. In later years he had less time to devote to the practical side of the work, though he followed with great interest the development of both aerial and colour photography.

Pope had a natural aptitude for acquiring foreign languages, in which capacity he was of assistance to his father, who was interested in the manufacture of bricks in Belgium and their export to this country. He became proficient in both French and German whilst still in his teens and at the age of 15 was using a book of German mathematical tables, which was lying on his study desk at the time of his death. His fluent French and German proved invaluable in later years and singled him out to represent this country with significant success at international conferences called for the discussion of chemical theories and industries.

He took no part in sport, a circumstance probably attributable to an eyesight defective from childhood, but he was a prodigious walker and particularly interested in matters relating to dogs and birds. He was a capable violinist and for many years played in an amateur orchestra. In later life his work afforded him little leisure for this recreation.

He left school in August, 1885, having obtained full marks at the midsummer examination in both Theoretical and Practical Chemistry and being recorded as specially distinguished in " Theory of Music ". He was given an entrance scholarship at the Finsbury Technical College, where he worked till 1887 when he was awarded a Mitchell Scholarship tenable at the City and Guilds College, South Kensington. Here he at once attracted the attention of Armstrong, who, on Pope's receiving the Associateship of the College, made him a member of his staff. In 1897 he was appointed as chief of the Chemistry Department of the Goldsmiths' Company's Institute at New Cross and was thus brought into contact with the Clerk of the Company, Mr. W. T. (later Sir Walter) Prideaux. The Goldsmiths' Company over a long period of years has shown its practical interest in the advancement of Chemistry. In this connection it may be remembered that when in 1886 Longstaff offered £1,000 to the Chemical Society towards the establishment of a Research Fund provided others would make up a like amount, the Court of the Company forthwith contributed the whole sum required. Pope's work at the Institute and his long association with the City and Guilds Colleges, which owe so much to the munificence and fostering care of the Goldsmiths, led ultimately to his being given the Freedom and Livery of the Company by special grant in 1919. Two years later he was elected a member of the Court and in 1928—29 served as Prime Warden. His collaboration then became most valuable in assuring that the large sums voted by the Company for technical education should be applied to the fullest advantage. Pope interested himself in all questions relating to gold and silver plate and to the Hall Marking laws. He presided at many meetings organised by the Company to consider matters affecting the manufacture of silver. At these discussions his wide knowledge of the industry and his unfailing tact helped greatly in securing agreement and in solving the difficulties which arose from time to time. In 1922 the Company appointed him one of their representatives on the Council and the Executive Committee of the City and Guilds Institute. Ten years later he accepted the Chairmanship of the Council, a position he occupied with great distinction till his death.

Pope was appointed head of the Chemistry Department of the Municipal School of Technology and Professor of Chemistry at Manchester in 1901 and seven years later was elected to the Chair of Chemistry at Cambridge in succession to the veteran Liveing. His voluminous scientific work is outlined elsewhere, but it is noteworthy that he had the none too common gift of being able to apply his knowledge in the interests of the community. This was recognised during the world war when he became a member of the panel of consultants of Lord Fisher's Board of Invention and Research. He devoted himself wholeheartedly and with consummate skill to those chemical problems arising from the war, towards the solution of which his vast knowledge, acquired by wide reading, proved of



W. J. Pope

[*To Face p. 698.*

the utmost value, particularly in connection with the sources of materials needed for high explosives. Later, when the Germans used poison gas, he developed the ethylene process for the direct synthesis of mustard gas. At the end of the war these services were recognised by his receiving a Knighthood of the Order of the British Empire.

As a lecturer he had the flair which combines easy delivery with clear statements and invariably attracted the closest attention of his audience. In the laboratory his methods developed initiative, to which he gave full encouragement and active support whilst interfering with the worker as little as possible. In this way he succeeded not only in winning the confidence of his staff and students but also in obtaining the best results from their work. But Pope was other than a mere academic professor, for he possessed marked power of organisation. In his address from the Presidential Chair of the Chemical Society in 1918 he directed attention to the urgency of bringing into line the societies representing pure and applied chemistry, and later was largely instrumental in forming the Federal Council for Pure and Applied Chemistry, of which he served as the first Chairman. In collaboration with leading chemists on the Continent he created the *Union Internationale de Chimie* having the like object of co-ordinating the work of societies of different nationalities. He was President of this federation in 1923, when many distinguished British and foreign chemists attended the Fourth International Chemical Conference, held in Cambridge. He also presided during a long period of years at the Chemical Conferences of the Solvay Foundation in Brussels. His services to this Foundation were recognised in 1937 when he was created a *Grand Officier de l'Ordre de Leopold.* He was awarded many medals, including the Davy Medal of the Royal Society, numerous Honorary Degrees of Universities and the Membership of leading English and foreign Scientific Societies. With all these high distinctions he referred to none with greater pleasure than to the first medal he received whilst still a boy and a student at Finsbury, a bronze medal for distinction in Coal Tar Products awarded at the examinations of the City and Guilds of London Institute.

In his later years Pope would often refer to himself as a machine, a most unsuitable description of a man characterised by his broad outlook. Always willing to afford help to friends and colleagues in any matter in which he could assist, many of those with whom he associated made serious claims on his time. He systematically over-worked himself and was left little opportunity for leisurely enjoyment of hobbies. None the less he was able at times to attend sales at Christie's and elsewhere and thus to add to his almost unique collection of chemical paintings and engravings and of medieval pharmaceutical jars and mortars. Pope's interests were unusually wide. He was equally at home at the Garrick Club with his theatrical friends as when he was presiding over an international gathering of eminent chemists. He was invariably full of humour, which was whetted by his critical faculty. No more amusing example of this can be cited than his letter to *The Times* on American safety razor blades. The works manager of a Sheffield firm had given evidence before the Standing Committee of the Board of Trade on imported cutlery, in which he had stated that the total annual import of one type of American safety razor blades if spread out would cover England eight times over. This was widely reported in and accepted by the Press without comment, until Pope's letter, appearing a few days later, in innocently worded terms pointed out *inter alia* that if the contention of the witness was taken seriously, as no doubt it should be, it disclosed who paid the supertax, since each inhabitant of the country must be spending more than £150,000 per annum on safety razor blades.

Pope was a bachelor. As a genial and considerate host he will be best remembered by his friends. In his own home and amongst intimates the air of concentration often mistaken for gloom was absent and he showed himself human and entertaining. He was a raconteur of delightful stories, which might have emanated from some eminent actor or ambassador rather than from a learned chemist. Modest in mien and an authority in every branch of his own subject, Pope showed remarkable versatility. This made him a delightful companion even amongst those who had no training in chemistry, whilst his fellow chemists often failed to recognise that he was well versed in questions relating to literature and to art. The passing of his engaging personality leaves a void amongst his friends which cannot be filled. No longer will they be able to enjoy association with one of whom it may truly be said, he passed through life :—

> " Wearing all that weight
> Of learning lightly like a flower."

GERALD T. MOODY.

POPE began his scientific career at the Central Technical College (then the City and Guilds of London Central Institution) in a most stimulating environment. Armstrong was at the height of his powers. His well-known views on aromatic substitution and on the origin of colour had recently been put forward and investigations on these subjects were being actively pursued in his laboratory. But though this work was claiming most of his attention, he still maintained his interest in the chemistry of camphor and the terpenes and Pope's first scientific publication was a joint paper with him on an investigation in this field.

It had been generally supposed that turpentines from different sources differed because they contained different terpenes. Armstrong, however, thought that they contained different proportions of the antimeric forms of the same terpene. Since the terebenthene (pinene) from French oil of turpentine showed a uniform high lævorotation and that from the American oil a smaller and variable dextrorotation, Armstrong suspected that the French oil was practically pure *l*-pinene and the American a mixture of *d*- and *l*-pinene with the former in greater or less excess. He was strengthened in this belief by finding that an oil of turpentine from the Burmese *Pinus Khasyana* (received from Kew) was apparently the optical counterpart of the French oil.

Seeking some characteristic crystalline derivative through which pinene could be identified, he thought of utilising the old observation of Sobrero (1851) that the terpene fraction of oil of turpentine yielded a solid compound, $C_{10}H_{18}O_2$, on prolonged exposure to moist oxygen in sunlight. For this compound Armstrong proposed the name *sobrerol* and he and Pope studied the production of sobrerol from turpentines of different origin (J., 1891, **59**, 315).

They showed that sobrerol was an optically active compound and that the optical antimers crystallised in enantiomorphous hemihedral forms and combined to give a racemic modification. French turpentine yielded nearly pure *l*-sobrerol and Burmese pure *d*-sobrerol. The American oil, however, gave mixtures partially separable by crystallisation, the earlier fractions being pure *d*-sobrerol, the later containing increasing proportions of *l*-sobrerol. Armstrong's views on the nature of the terpenes in these turpentines were thus confirmed.

The value of the paper depended largely on the crystallographic observations and for these Pope was responsible. In an explanatory paper (*ibid.*, p. 311) preceding the joint publication Armstrong made the acknowledgment that the possibility of " collating the scattered results of earlier work " had been " chiefly owing to the important assistance which one of my students, Mr. Pope, has rendered me in submitting the products to crystallographic examination."

About the time that this work was finished Marsh and Cousins published an account of the preparation of sulphonic derivatives of chloro- and bromo-camphor by means of chlorosulphonic acid (J., 1891, **59**, 966). As Armstrong had long been interested in the action of sulphuric acid on camphor—he had worked on this subject with A. K. Miller many years previously (*Ber.*, 1883, **16**, 2255)—he asked Pope to repeat Marsh and Cousins' work.

Pope's first attempts were not very successful. They resulted in a tar-like product which he took in a porcelain basin to his colleague, F. S. Kipping, then newly arrived from the Heriot Watt College, Edinburgh, where he had been with W. H. Perkin. This was the beginning of a collaboration which lasted for several years and had an important effect in determining the subsequent direction of Pope's work.

It was known that camphor could not be sulphonated by ordinary concentrated sulphuric acid, for this converts it into " camphren ", shown by Armstrong and Kipping to be a mixture, chiefly of carvenone and 3 : 4-dimethylacetophenone (J., 1893, **63**, 75). Kipping and Pope found, however, that it was sulphonated by fuming sulphuric acid and also, as had been found by Marsh and Cousins for the halogenocamphors, by chlorosulphonic acid. They soon discovered that the sulphochlorides, described by Marsh and Cousins as non-crystallisable, were in fact when pure substances of exceptional crystallising power. The same was true of many of their derivatives (J., 1893, **63**, 548; 1895, **67**, 354).

Pope was thus afforded abundant opportunity to develop his great talent as a crystallographer. Most of his earlier work was strongly influenced by his interest in crystallography, and Professor F. S. Kipping says, " I think that the happiest hours of his life were those spent in the dark room with his goniometer, in calculating the results of his measurements and in drawing the crystal figures. He seemed never to tire of this work and his desire for new compounds to measure was almost insatiable."

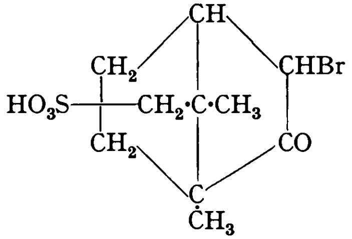
Kipping and Pope further discovered that the camphorsulphochlorides and bromides, when heated, decomposed smoothly with the elimination of sulphur dioxide, forming halogenocamphors. These derivatives were different from those formed by the direct halogenation of camphor and were named " from their pyrogenic formation " π-derivatives (J., 1895, **67**, 371).

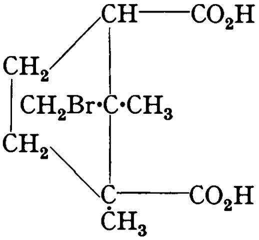
By degradation of bromocamphorsulphonic acid Kipping was able to effect transformations which evidently involved the following structural changes :

$$-CH_2{\cdot}SO_3H \longrightarrow -CH_2Br \longrightarrow -CO_2H$$

Sulphonation had therefore taken place in a methyl group, and, since the carboxyl finally produced was on a different carbon atom from either carboxyl of camphoric acid, the methyl group sulphonated was one of those of the *gem*-dimethyl group. On the basis of the Bredt camphor formula α-bromo-π-camphorsulphonic acid therefore had the structure (I).

(I.)





(II.)

Oxidation of απ-dibromocamphor gave π-bromocamphoric acid (II), which, treated with alkali, yielded a *trans*-lactone. The π-position is therefore in the methyl group of the *gem*-dimethyl pair remote from the carbonyl group (J., 1896, **69**, 913).

By these discoveries the preparation of many new halogeno-derivatives of camphor became possible and seven such compounds were prepared and characterised. The study of these substances, besides revealing crystallographic relationships, led to various observations of theoretical interest. Thus, *d*-camphor when sulphonated underwent racemisation, yielding a mixture of *d*- and *l*-camphorsulphonic acids. Kipping and Pope pointed out the surprising character of this observation (J., 1897, **71**, 956). Profound intramolecular changes would be needed for the inversion of a tricyclic compound of the Bredt formula. Kipping and Pope considered that the racemisation showed " that part of one closed carbon chain may be caused to rotate about another," but it is difficult to believe that a change of this kind could be brought about by thermal processes at 100° and one is tempted to look for some chemical mechanism. Racemisation of camphor would result from migration of the carbonyl group between positions 2 and 6, and it is conceivable that in heating with fuming sulphuric acid or chlorosulphonic acid transformations of the retropinacol, pinacone, and other types might occur through which such a change could be effected.

Another result of these investigations was the discovery of *pseudo-racemism* (J., 1897, **71**, 989). This resulted from the crystallographic comparison of the optically active and inactive forms of two compounds obtained by the degradation of bromocamphorsulphonic acid, *trans*-camphotricarboxylic anhydride and *trans*-π-camphanic acid hydrate. The inactive forms of these substances were found to resemble their active components in crystalline characters so closely as to make their crystallographic distinction difficult. The same phenomenon was shown by camphorsulphonyl chloride. Since the racemic and the optically active modifications of a substance must differ markedly in crystal structure, the inactive compounds could scarcely be normal racemates. Further investigation showed that they were conglomerates of a peculiar type formed of alternate twined layers of the enantiomorphs. For non-homogeneous crystalline associations of enantiomorphs of this kind Kipping and Pope proposed the name *pseudo-racemate*. The sense in which pseudo-racemism was understood by the originators of the word is thus very different from that in which it was subsequently employed by Roozeboom, who used the term to denote a homogeneous solid solution of enantiomorphs.

An investigation which combined Pope's two chief interests—stereochemistry and crystallography—was concerned with the crystallisation of sodium chlorate (J., 1898, **73**, 606). In substances like this, which have a symmetrical molecule but crystallise in enantiomorphous forms, the configuration (*d*- or *l*-) assumed by any given crystal must be determined by chance. The relative probability of production of *d*- and *l*-crystals might therefore prove easily susceptible of influence by an asymmetric environment. This was found to be the case. When sodium chlorate crystallised from pure water, the numbers of *d*- and *l*-crystals deposited were shown to be equal within the limits of experimental error. Addition of glucose, however, brought about a remarkable disproportion in the numbers of the two forms produced, a large excess of *l*-crystals being deposited. In crystallisations from solutions containing 200 g. of glucose per litre the mean ratio found was 32% of *d*- to 68% of *l*-crystals.

To show that the effect was due to the enantiomorphism of the added glucose and was not directly related to its optical activity a similar series of experiments was carried out with *d*-mannitol, which is practically inactive in aqueous solution. The directive effect of mannitol on the crystallisation of sodium chlorate was found to be at least as great as that of glucose.

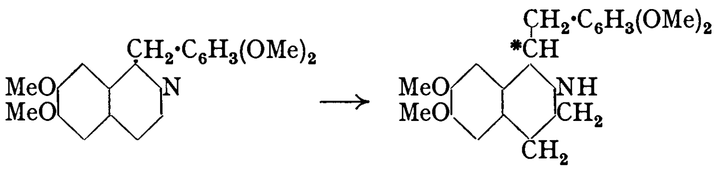
The results of some rather similar experiments on sodium ammonium racemate were not published until several years later (J., 1909, **95**, 103). When aqueous solutions of sodium ammonium racemate were allowed to evaporate spontaneously in open beakers so that only a few large crystals separated, the deposits consisted in the main of sodium ammonium *d*-tartrate, the *l*-tartrate remaining supersaturated in the solution. This preferential deposition of the *d*-tartrate was doubtless due to inoculation of the solution by *d*-tartrate particles present in the laboratory atmosphere, though Kipping and Pope also suggested as a possible alternative cause the presence in the racemate of a minute excess of *d*-tartrate. Deposits consisting of numerous small crystals usually showed little or no activity. Atropine sulphate was subsequently found by Anderson and Hill to show a similar behaviour (J., 1928, 993).

This fruitful partnership was brought to an end by Kipping's appointment to the Professorship of Chemistry at University College, Nottingham, and shortly afterwards Pope went as Head of the Chemical Department to the Goldsmiths' Institute at New Cross.

Goldsmiths' Institute, New Cross. 1897—1901.

Here he threw himself into research with intense activity. He inspired an enthusiastic band of workers—among them S. J. Peachey and A. W. Harvey—and papers poured from his laboratory in a rapid stream.

One of his first investigations—carried out with Peachey—was on the optical resolution of " tetrahydropapaverine " (J., 1898, **73**, 893, 902). Its object was to illustrate the way in which stereochemical methods could be used for the determination of structure. According to the formula which Goldschmiedt had proposed for papaverine (*Monatsh.*, 1888, **9**, 778) the alkaloid itself (in accordance with its optical inactivity) contained no asymmetric carbon atom, but one should be generated in the reduction to tetrahydropapaverine.



The optical resolution of the inactive tetrahydro-derivative would therefore provide confirmatory evidence for Goldschmiedt's formula. Goldschmiedt's " tetrahydropapaverine " was in fact, as was afterwards found by Pyman (J., 1909, **95**, 1610), a dihydro-derivative, but Pope and Peachey showed that it could be resolved and thus made an important contribution to the evidence for its constitution. The resolution was, however, not effected without difficulty and the method by which the solution of the problem was achieved was to lead to far-reaching results.

Till then the only acid employed for the resolution of bases had been tartaric acid, but this proved to be useless for the resolution of " tetrahydropapaverine ", since the crystalline tartrate was homogeneous. It was a partial racemate in which one molecule of *d*-tartaric acid was combined with one molecule of the *d*- and one of the *l*-base.

In seeking a means of getting round this difficulty it was natural that Pope should think of the camphorsulphonic acids with which his earlier work had made him so familiar. They were strong acids, forming stable salts even with weak bases. They were monobasic and thus free from the disadvantages connected with the dibasicity of tartaric acid. Also their salts usually crystallised exceedingly well. Accordingly the bromocamphorsulphonate of " tetrahydropapaverine " was investigated and was found to be easily resolvable. Chlorocamphorsulphonic acid could also be used for the resolution of the base but was less convenient.

The camphorsulphonic acids were then applied to the resolution of other externally compensated bases. Tetrahydroquinaldine, tetrahydro-*p*-toluquinaldine and *ac*-tetrahydro-β-naphthylamine were all split into optically active components and from each of these investigations some point of general interest emerged.

For the resolution of tetrahydroquinaldine Pope (with Peachey) described a device which he termed " the equilibrium method ". It consisted in using enough only of the optically active acid to combine with one of the two components of the externally compensated base, an acid such as hydrochloric being added to combine with the other component. The method was especially effective when the required salt was sparingly soluble.

In connexion with the resolution of tetrahydro-*p*-toluquinaldine a useful procedure was described for surmounting the difficulty of isolating the component which forms the more soluble salt with the resolving agent. It depended on the fact that the component with the more soluble bromocamphorsulphonate not infrequently gave the less soluble salt with Reychler's camphorsulphonic acid. Thus, after separation of the pure *d*-bromocamphorsulphonate of the *l*-base, the mother-liquors were treated with alkali, and the liberated base converted into β-camphorsulphonate. Crystallisation of this readily gave the *d*-base *d*-camphorsulphonate (J., 1899, **75**, 1093).

Finally, in studying the resolution of *ac*-tetrahydro-β-naphthylamine, Pope and Harvey made the surprising observation that extensive optical inversion occurred when salts of the optically active base were treated with alkalis (J., 1901, **79**, 94). There is no evident mechanism by which the inversion could be brought about, for the explanation suggested by Pope and Harvey is scarcely tenable in the light of present knowledge, and the question invites further investigation.

After the efficacy of the camphorsulphonic acids as resolving agents had been established Pope lost no time in applying them to one of the outstanding questions of the day—the possibility of obtaining optically active asymmetric nitrogen compounds. The subject was at that particular time receiving great attention. Marckwald and von Droste-Huelshoff (*Ber.*, 1899, **32**, 560) had just carried out an exceedingly careful examination of Le Bel's claim (*Compt. rend.*, 1891, **112**, 724) to have obtained an optically active quaternary ammonium salt by growing a micro-organism in a solution of methylethylpropyl*iso*butylammonium chloride and had been entirely unable to confirm his results. Le Bel had quickly replied (*ibid.*, 1899, **129**, 548), amplifying and confirming his former observations. However, many years later Pope and Read (J., 1912, **101**, 519) carried out a very carefully controlled preparation of methylethylpropyl*iso*butylammonium iodide and found Le Bel's description so much at variance with the facts that they were forced to the conclusion that Le Bel never obtained this compound and that the slight optical activity he had observed was to be ascribed to some impurity introduced with, or formed by, the micro-organism.

Besides using biochemical methods, Marckwald and von Droste-Huelshoff had endeavoured to resolve methylethylpropyl*iso*butylammonium by means of its tartrate, camphorate, and mandelate, but without success. Wedekind also was actively engaged on the same subject (*Ber.*, 1899, **32**, 517). He had prepared a new quaternary ammonium salt containing four different hydrocarbon radicals—benzylphenylallylmethylammonium iodide—but all his attempts to resolve it with the aid of tartaric or camphoric acid had failed.

Pope then, with Peachey's assistance, made benzylphenylallylmethylammonium iodide by Wedekind's method, converted it into the camphorsulphonate, and immediately found that this was resolvable into diastereoisomers from which the optically active *d*- and *l*-quaternary ammonium iodides and bromides could be prepared, thus proving " that quaternary ammonium derivatives in which the five substituting groups are different, contain an asymmetric nitrogen atom which gives rise to antipodal relationships of the same kind as those correlated with an asymmetric carbon atom " (J., 1899, **75**, 1127; **1901**, **79**, 828).

The production of optically active ammonium salts was quickly followed by the resolution of asymmetric compounds of sulphur (Pope and Peachey, J., 1900, **77**, 1072) and of selenium (Pope and Neville, J., 1902, **81**, 1552). The sulphur compound resolved was methylethylthetine bromide, $CO_2H{\cdot}CH_2{\cdot}SMeEtBr$, and the selenium compound the analogous phenylmethylselenetine bromide, $CO_2H{\cdot}CH_2{\cdot}SePhMeBr$, both resolutions being effected by means of bromocamphorsulphonic acid.

The search for a suitable selenium derivative brought out an interesting point in the chemistry of selenium. Phenyl methyl sulphide is incapable of combining with bromoacetic acid to form a thetine bromide, but Pope suspected that, since thio-ethers are more basic than ethers, selenides might be still more basic, and this proved to be correct, for phenyl methyl selenide was found to combine readily with bromoacetic acid. An increasing tendency to " onium compound " formation in the triad, oxygen, sulphur, selenium, was thus demonstrated.

At the same time he was working with Peachey on the production of optically active asymmetric tin compounds (Proc., 1900, **16**, 42, 116). The problem of finding suitable material was solved by the discovery of an elegant series of reactions by which the trimethyltin iodide of Ladenburg and Cahours could be converted into methylethylpropyltin iodide :

$$Me_3SnI \xrightarrow{ZnEt_2} EtMe_3Sn \xrightarrow{I_2} EtMe_2SnI \xrightarrow{ZnPr_2} PrEtMe_2Sn \xrightarrow{I_2} PrEtMeSnI$$

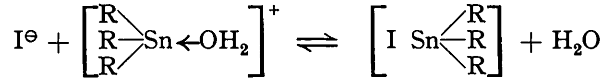
The latter compound was a liquid volatile without decomposition and soluble in non-polar solvents. It thus contained iodine covalently bound, but it gave with silver *d*-camphorsulphonate a camphorsulphonate which was soluble in water and was evidently a true salt. When an aqueous solution of this salt was evaporated to dryness, it was completely converted into *d*-methylethylpropyltin *d*-camphorsulphonate. This was the first recorded example of a phenomenon of which several instances have been since observed—the activation of an easily racemised radical by separation from solution in combination with an optically active complex. On treating the aqueous solution of the activated camphorsulphonate with potassium iodide, dextrorotatory methylethylpropyltin iodide was precipitated. Exactly similar phenomena were observed with the bromocamphorsulphonate. The rotation of the active iodide was variable on account of the ready racemisation, but the investigation gave decisive proof of the optical activity of asymmetric tin.

This series of researches, following one another in such rapid succession, attracted wide attention. The discovery that the valencies of other elements besides carbon had sufficient configurational stability to give observable optical activity in their asymmetrical combinations was immediately recognised as one of the first importance and it gained for Pope an established position in the front rank of scientific investigators.

The work was done at a time when the distinction between electrovalency and covalency was imperfectly understood, and the optically active compounds of quadrivalent sulphur, selenium, and tin were regarded as formally analogous to compounds of asymmetric quadrivalent carbon. Nevertheless Pope fully realised that the compounds were salts and that they must be held to ionise, and he drew attention to the surprising fact that the optically active ions maintained an asymmetric configuration although three radicals only were attached to the central atom (J., 1901, **79**, 840).

The case of tin is, however, fundamentally different from that of sulphur or selenium. The sulphonium and selenonium ions $[SR_3]^+$ and $[SeR_3]^+$ are presumably analogous in electronic structure and in configuration to the phosphine and arsine molecules PR_3 and AsR_3 and these, like ammonia and the amines, are known to be nonplanar. The trialkyltin cation $[SnR_3]^+$, however, would be expected to correspond in configuration with the molecule of a trialkyl derivative of a Group III element and these molecules, like that of boron trimethide, are doubtless planar.

In an ion $[SnR_3]^+$, however, the tin atom would have an incomplete valency shell and, like boron in its 3-covalent compounds, should show a great tendency to co-ordination. It would seem possible, therefore, that Pope and Peachey's camphorsulphonate, prepared in aqueous solution, may have contained a cation of the type $[R_3Sn \leftarrow OH_2]^+$ having a tetrahedral configuration and reacting with an iodide ion, probably with inversion, to give a tetrahedral covalent iodide :



The physiological activity of some of the compounds employed in these investigations caused a good deal of inconvenience. The vapour of the trialkyltin iodides gave rise to various unpleasant symptoms and on this account the work on optically active tin had to be curtailed and the account of the work was limited to two papers in the Society's Proceedings.

The tenacious odour of the organic selenides was also very troublesome. On Kipping's visits to London he and Pope generally arranged to meet. Professor Kipping says " We usually dined together at Frascati's, but my delight in his company was somewhat tempered by the perfume of the selenium or tellurium compounds with which he had been working and which persisted even after he had discarded his laboratory clothes. He told me gleefully that when going home from New Cross, even if he started with a full compartment, he would be the sole occupant of the railway carriage before many stations had been passed."

Soon after his appointment to the Cambridge professorship he again began work on selenium. He proposed to prepare the optically active methylethylselenetine bromide in order to compare its molecular rotation with that of methylethylthetine bromide, and thus find the effect of the change in the central atom on the rotatory power of asymmetric molecules otherwise identical.

A mysterious odour soon appeared and pervaded a considerable area of the town. The Borough authorities became gravely concerned, suspecting the newly installed sewerage system. It was all the more unfortunate since the Darwin Centenary celebrations were just about to begin. At length the smell was traced to its source in the University Chemical Laboratory and that evening the discovery was made known in the *Cambridge Daily News* under the head-line " Drains exonerated. Science the Sinner." An expedition was then equipped with the necessary apparatus and Pope and Read, with assistants, proceeded down the Cam beyond Clayhithe and in a lonely meadow by the river carried through the most malodorous stage of the process. But even then the smell could not be kept within bounds and the work had to be abandoned.

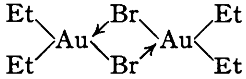
Municipal School of Technology, Manchester. 1901—1908.

At Manchester Pope's work proceeded at first on the lines which he had been pursuing at New Cross. He completed the work with Neville on optically active selenetines. He continued his studies on the resolution of cyclic bases, with Clark (J., 1904, **85**, 1330) resolving α-methyldihydroindole, which was found to differ from tetrahydro-β-naphthylamine in that there was no racemisation when the salts of the active base were treated with alkali, and with Beck (J., 1907, **91**, 458) employing the α-bromo-β-camphorsulphonic acid of Armstrong and Lowry for a new resolution of tetrahydro-*p*-toluquinaldine in order to show the efficacy of the acid as a resolving agent.

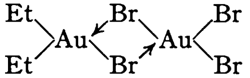
With Peachey he continued the work on the organic compounds of tin and this led to new developments (Proc., 1903, **19**, 290). For the conversion of trialkyltin halides into tetra-alkylstannanes Pope and Peachey had formerly used zinc alkyls. As they had not found them very satisfactory, they now tried instead the organomagnesium halides discovered a year or two previously by Grignard. These proved far more convenient and effective than zinc alkyls and by following up this observation they were led to discoveries of much interest.

By treating platinic chloride with methylmagnesium iodide they succeeded in obtaining a series of organo-metallic derivatives of platinum (J., 1909, **95**, 571) and, in a similar manner, Pope and C. S. Gibson prepared from auric chloride alkyl derivatives of gold (J., 1907, **91**, 2061). Thus for the first time it was shown that noble metals were capable of combining with alkyl radicals and Pope and Peachey's platinum derivatives are still the only compounds known in which a transitional element is linked to alkyl groups.

The platinum compounds were of the type Me_3PtX, where X was a negative radical such as iodine or NO_3. The gold compounds had the empirical formulæ Et_2AuBr and $EtAuBr_2$, but Gibson and his co-workers subsequently showed that these formulæ must be doubled to give the molecular formulæ, the substances having the constitutions :



and

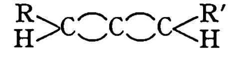


Conspicuous among the scientific publications issuing from Pope's laboratory during this period were the elaborate memoirs on the relations between chemical constitution and crystal structure in which W. Barlow and he developed the theory generally known as the valency-volume theory of crystal structure (J., 1906, **89**, 1675; 1907, **91**, 1150; 1908, **93**, 1528; 1910, **97**, 2308). Barlow had long been interested in the geometrical problems presented by the packing of spheres on account of their relation to the arrangement of atoms in crystals. As far back as 1883 he had discovered the two ways—the cubic and the hexagonal—in which equal spheres could be arranged in closest packing. In 1906 he and Pope made the new hypothesis that the space which an atom occupies in a crystal is proportional to its valency. Using this hypothesis in combination with the principle of close packing, taking also into account the information obtainable from crystallographic examination, they endeavoured to deduce the crystal structure of many typical substances. In earlier attempts to gain an insight into the structure of crystals the lattice points had been supposed to correspond with the chemical molecules. In the Barlow–Pope method of approach atoms were centred on the lattice points and the close-packed assemblage of atoms was then partitioned into molecules.

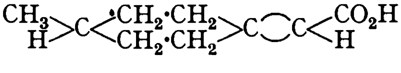
Although the postulate of the proportionality of volume and valency cannot now be maintained, there was much in these memoirs which foreshadowed present views of crystal structure based on the knowledge gained through *X*-ray analysis. This is true particularly with regard to substances like the metallic elements and the alkali-metal halides in which the valency forces are non-directional and the arrangement of the atoms in the crystals is largely determined by the requirements of close packing.

The outstanding investigation initiated in the Manchester period was that on methyl*cyclo*hexylideneacetic acid. The conception of the asymmetric carbon atom was so easily applicable and had proved so sure a guide in dealing with mirror-image isomerism that in the minds of many organic chemists it had come to overshadow the fundamental principle of molecular dissymmetry on which it had been based. Pope conceived the brilliant idea of producing a compound which should be optically active and yet contain no asymmetric carbon atom in its molecule—at least, none in the ordinary sense. To realise this idea he devised a molecular type which might be regarded as derived from a disubstituted allene (III) by expansion of one of the ethylene residues into a *cyclo*hexane ring.

(III.)



$$\begin{matrix}R\\H\end{matrix}\!>C=C=C<\!\begin{matrix}R'\\H\end{matrix}$$



$$\begin{matrix}CH_3\\H\end{matrix}\!>C<\!\begin{matrix}CH_2\cdot CH_2\\CH_2\cdot CH_2\end{matrix}\!>C=C<\!\begin{matrix}CO_2H\\H\end{matrix}$$

(IV.)

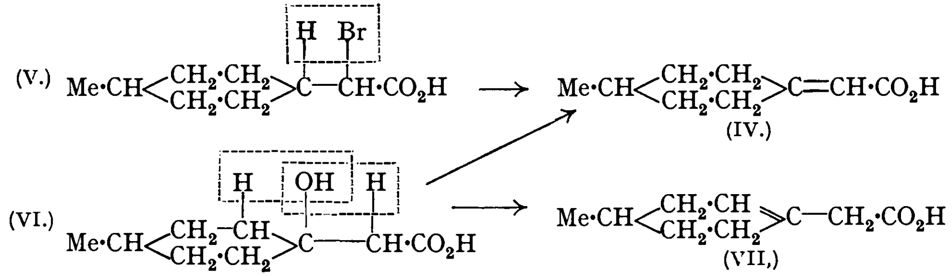
With convenient substituents this gave methyl*cyclo*hexylideneacetic acid (IV). Although in this compound no carbon atom is attached to more than three unlike atoms or groups, a tetrahedral arrangement of the carbon valencies makes its molecule non-superposable upon its mirror-image. It should therefore exist in two enantiomorphous modifications.

For the production of this compound he secured the collaboration of W. H. Perkin, who then occupied the chair of Organic Chemistry in the University of Manchester, and a process for its synthesis was described in a joint paper in 1908 (J., 1908, **93**, 1075), a preliminary account having been published in 1906.

By a remarkable coincidence Marckwald and Meth were at the same time engaged on the synthesis of this very compound for the same purpose (*Ber.*, 1906, **39**, 1171, 2404). They prepared an acid which they believed to be methyl*cyclo*hexylideneacetic acid and succeeded in resolving it into optically active components. It was, however, different from Perkin and Pope's acid.

Perkin and Pope's acid was obtained by the elimination of hydrogen bromide from the compound (V). The elimination could take place in one way only and the constitution of the acid was therefore definitely fixed by its synthesis. Perkin and Pope's acid was unquestionably methyl*cyclo*hexylideneacetic acid (IV).

Marckwald and Meth's acid was obtained by the elimination of water from the compound (VI). This substance could lose water in two ways, forming a double bond either in the semicyclic position (IV) or in an endocyclic position (VII). Since the resulting compound


(V.) $\mathrm{Me{\cdot}CH{<}^{CH_2{\cdot}CH_2}_{CH_2{\cdot}CH_2}{>}CBr{-}CH_2{\cdot}CO_2H} \longrightarrow$ $\mathrm{Me{\cdot}CH{<}^{CH_2{\cdot}CH_2}_{CH_2{\cdot}CH_2}{>}C{=}CH{\cdot}CO_2H}$ (IV.)

(VI.) $\mathrm{Me{\cdot}CH{<}^{CH_2{-}CH_2}_{CH_2{\cdot}CH_2}{>}C(OH){-}CH_2{\cdot}CO_2H} \longrightarrow$ $\mathrm{Me{\cdot}CH{<}^{CH_2{\cdot}CH}_{CH_2{\cdot}CH_2}{>}C{-}CH_2{\cdot}CO_2H}$ (VII.)

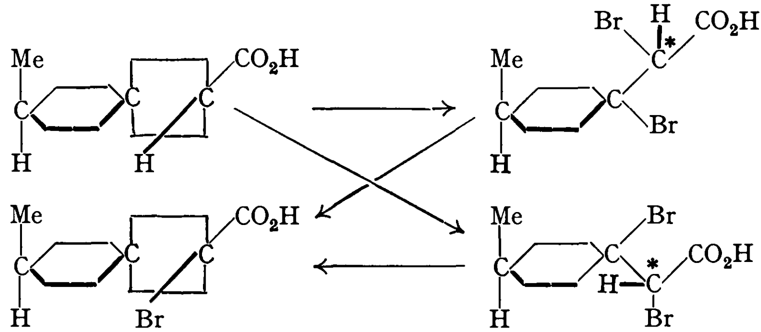
was different from Perkin and Pope's acid, the elimination must have taken place in the second way (notwithstanding evidence obtained by Marckwald and Meth which, superficially considered, seemed to indicate that the double bond was in the semicyclic position). Marckwald and Meth's acid was therefore methyl*cyclo*hexeneacetic acid (VII). This compound contains an ordinary asymmetric carbon atom and no special interest attaches to its resolution.

Although Perkin and Pope's process gave the right acid, it involved several difficult operations and it could not easily be made to yield enough of the substance for resolution. Shortly afterwards, however, Wallach in Göttingen chanced on a simpler synthesis. He found that the way in which water was eliminated from β-hydroxy-acids of the type (VI) depended on the nature of the dehydrating agent used. Strongly acid dehydrating agents like potassium bisulphate, phosphoric oxide, or the dilute sulphuric acid used by Marckwald and Meth, led to the formation of a double bond in the endocyclic position. Acetic anhydride, on the other hand, gave a semicyclic double bond. Methyl*cyclo*hexylideneacetic acid could therefore be obtained with comparative readiness by heating the compound (VI) with acetic anhydride.

Wallach thereupon informed Perkin that he had got a method by which the acid could be made in quantity. He was not prepared to divulge the method, but he sent Perkin some of the acid and in return his name was to be included in the title of the paper.

On December 18th, 1908, Perkin wrote to Pope, then established at Cambridge : " The whole of the acid (now about 25 grams, originally 30 grams) I have sent on to you for you to see whether you can get anything optically active out of it. If not, the question arises, What other differences may the two enantiomorphous modifications possibly exhibit and how can we prove these experimentally? The problem must surely be a very interesting one whichever way it goes." The solution of the problem was not long in coming. The acid was shown to be resolvable into optically active components. This final realisation of Pope's idea was accomplished with the assistance of Dr. John Read, now Professor of Chemistry at St. Andrews, and the rotatory power of the active modifications of the acid proved to be quite considerable ($[\alpha]_D \pm 81°$). The resolution presented unusual difficulty. The salts of the acid with the alkaloids and other optically active bases showed the greatest reluctance to crystallise * and when the brucine salt had at length been obtained crystalline the separation of the salts of the *d*- and *l*-acids was greatly impeded by their mutual solubility in the solid state. By an exceptional arrangement the account of the resolution was published simultaneously in English and in German (J., 1909, **95**, 1789; *Annalen*, 1909, **381**, 180.)

In a later paper (J., 1911, **99**, 1510) Perkin and Pope described further work on the acid, in which, among other reactions, transformations of the "centroasymmetric" compound into compounds containing an ordinary asymmetric carbon atom were studied. Thus, the addition of bromine to the optically active *cyclo*hexylidene acid produced two optically active dibromo-acids (*cis-trans* isomerides, VIII and IX).



(VIII.)

(IX.)

(X.)

In these the molecular dissymmetry arises entirely from the newly formed asymmetric carbon atom C* (on the usual assumption of free rotation about a single bond) and the *cyclo*hexane ring is only concerned (through its 1 : 1 : 4-substitution) in the geometrical isomerism.

The rotations of the two dibromo-acids were found to be of opposite signs. The diagrams show how this probably comes about. Provided that the addition of bromine takes place in a corresponding manner (*i.e.*, by *cis*-addition or by *trans*-addition) in each case, the system $R\cdot CHBr\cdot CO_2H$ will have opposite configurations in the two isomerides. The diagrams are drawn on the assumption of *trans*-addition.

The isomeric dibromo-acids could be transformed back again into a centroasymmetric compound, for with potassium hydroxide they showed the normal behaviour of αβ-dibromo-acids, hydrogen bromide being eliminated with the formation of the α-bromo-αβ-unsaturated acid (X). Both dibromo-acids gave the same optically active methyl*cyclo*hexylidenebromoacetic acid and the rotation of the latter had the same sign as that of the original centroasymmetric acid.

Cambridge. 1908—1939.

In the period following the investigations on methyl*cyclo*hexylideneacetic acid Pope's work was chiefly centred on the stereochemistry of compounds of simple molecular constitution.

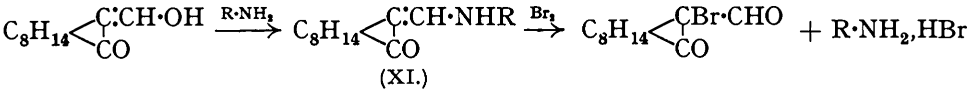
* Professor Read relates how the accomplishment of this exceptionally difficult task was helped by the remissness of a laboratory attendant. The boy neglected an instruction to clean up an accumulation of watch-glasses containing the results of many seemingly unsuccessful experiments and after two or three days he was sent for to be reprimanded. The glasses had stood, some of them for months, without any sign of crystallisation having been observed, but while awaiting the boy's arrival Read noticed a white speck in a glass containing a glassy film of brucine salt. The speck proved to be crystalline. It was effective in starting the crystallisation of the brucine salt in mass and thus it led ultimately to the resolution.

The question whether the simpler carbon compounds were capable of showing optical activity was first raised by Eiloart in his translation of van 't Hoff's "Arrangement of Atoms in Space" (1898, p. 25). Eiloart pointed out that in every optically active compound then known at least two other carbon atoms were directly linked to the asymmetric carbon atom, C–C*–C. There was therefore no experimental evidence that asymmetric compounds with less than three carbon atoms in the molecule could show optical activity and he suggested that in these simple compounds the radicals might be too mobile to permit the activity to be observed.

The question of the optical stability of simple molecules then seemed to Pope one of the most important unsolved problems of stereochemistry and he had already begun to work on it at Manchester. There, with Read, he had prepared chlorosulphoacetic acid, $CHCl(CO_2H)\cdot SO_3H$, and chlorobromomethanesulphonic acid, $CHClBr\cdot SO_3H$, both described by Andreasch in 1887, and had tried to resolve them. A number of crystalline salts with optically active alkaloids were obtained but none of them had proved resolvable (J., 1908, **93**, 794).

This failure might have been due, either to the mobility of the groups in these simple molecules, or to a special tendency of the alkaloidal salts of the simpler asymmetric acids to form partial racemates. Since he thought that the power to form partial racemates might occur less frequently in non-ionic compounds than in salts, Pope examined the possibility of avoiding the formation of these combinations by using non-ionic diastereoisomeric derivatives instead of diastereoisomeric salts for effecting resolutions.

With this object he and Read studied the condensation products (XI) which oxymethylenecamphor forms so readily with primary and secondary bases.



$$C_8H_{14}<\begin{matrix}C{:}CH\cdot OH\\ CO\end{matrix} \xrightarrow{R\cdot NH_2} C_8H_{14}<\begin{matrix}C{:}CH\cdot NHR\\ CO\end{matrix} \xrightarrow{Br_2} C_8H_{14}<\begin{matrix}CBr\cdot CHO\\ CO\end{matrix} + R\cdot NH_2,HBr$$

(XI.)

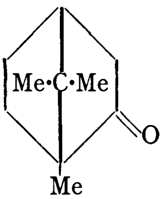
They examined a number of such products and found that externally compensated bases could in fact be resolved by means of them. *dl*-α-Phenylethylamine, for example, gave with *d*-oxymethylenecamphor two diastereoisomerides separable by fractional crystallisation, and from the separated diastereoisomerides the two enantiomorphous optically active bases could be obtained (J., 1909, **95**, 171; 1913, **103**, 444).

To regenerate the active bases from the condensation products an effective method was discovered consisting in treatment with bromine. Smooth fission into bromoformylcamphor and the hydrobromide of the base was thus brought about and by this device the process was made a practically useful method for resolving bases (J., 1912, **101**, 2337).

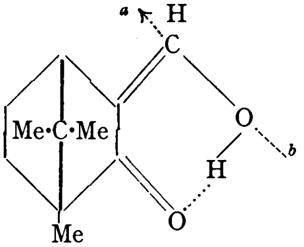
Further investigation showed, however, that it afforded no escape from partial racemism. When applied to the resolution of *dl*-tetrahydro-*p*-toluquinaldine, it failed (J., 1913, **103**, 1515). The *d*-methylenecamphor derivative of this base was not separable by fractional crystallisation into its diastereoisomeric components and the cause was the formation of a partial racemate. By combining the *d*- and the *l*-form of the base (readily obtained by resolution with bromocamphorsulphonic acid) with *d*- and with *l*-oxymethylenecamphor the four possible stereoisomeric forms of the condensation product were prepared and their crystalline combinations were studied in detail. Suitably paired, they gave not only the two fully racemic forms, but also four partial racemates, since *d*B*d*C (B representing the residue of the base and C that of methylenecamphor) formed crystalline combinations with both *l*B*d*C and *d*B*l*C, and the mirror images of these two combinations were of course formed by *l*B*l*C. Tetrahydro-*p*-toluquinaldinomethylenecamphor was thus shown to exist in no less than ten different crystalline stereoisomeric forms. These were all obtained in a state of purity and the investigation is probably the most complete study yet made of the racemic relationships of a pair of diastereoisomerides and their mirror images.

Since the molecular solubility of the individual diastereoisomerides was greater than that of any of their crystalline combinations, neither the base nor oxymethylenecamphor could be resolved by fractional crystallisation of their condensation product. The optically active forms of the base could nevertheless be obtained by means of oxymethylenecamphor in another way. *d*-Oxymethylenecamphor was found to react so much more rapidly with *l*- than with *d*-tetrahydro-*p*-toluquinaldine that the difference could be used for the resolution of the base.

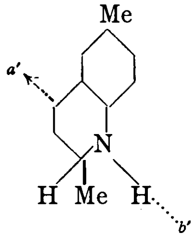
It may be remarked that through this difference in reaction velocities it should be possible to relate the configurations of *d*- and *l*-camphor to those of *d*- and *l*-tetrahydro-*p*-toluquinaldine. The difference is evidently due to unequal steric hindrance arising from the relative orientations of the α-methyl group of the base and the *gem*-dimethyl group of oxymethylenecamphor.



(XII.)



(XIII.)



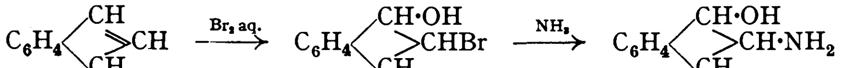
(XIV.)

If, in order to interact, the two molecules must (as would appear necessary) have the axes *ab a'b'* similarly directed, then it seems evident that (XIV) represents the form of tetrahydro-*p*-toluquinaldine in which the methyl group is so oriented as to cause the greater hindrance to interaction with the form (XIII) of oxymethylenecamphor. Hence, if (XII) is *d*-camphor, (XIV) is the form of the base which reacts the more slowly with *d*-oxymethylenecamphor, *viz.*, *d*-tetrahydro-*p*-toluquinaldine.

Since non-ionic diastereoisomerides could thus possess in a high degree the power to form partial racemates, it seemed unlikely that their use in place of salts would prove generally advantageous in resolutions. Pope therefore looked for other methods of resolving acids.

Though many more bases were available for resolving acids than acids for resolving bases, yet no base was known which was comparable in efficiency with the camphorsulphonic acids. He accordingly tried to find an optically active base which would correspond in effectiveness with these acids—that is to say, a base of great strength, giving salts of great crystallising power, and at the same time sufficiently easily obtainable.

With this object he and Read examined hydroxyhydrindamine, readily prepared from indene by the following reactions :



$$C_6H_4\left\langle\begin{matrix}CH\\ \\ CH_2\end{matrix}\right\rangle CH \xrightarrow{Br_2\,aq.} C_6H_4\left\langle\begin{matrix}CH{\cdot}OH\\ \\ CH_2\end{matrix}\right\rangle CHBr \xrightarrow{NH_3} C_6H_4\left\langle\begin{matrix}CH{\cdot}OH\\ \\ CH_2\end{matrix}\right\rangle CH{\cdot}NH_2$$

This compound was found to possess in a considerable degree the properties required. It was a strong organic base—strong enough to form a stable carbonate—most of its salts crystallised well and it was easily resolved with bromocamphorsulphonic acid (J., 1911, 99, 2071; 1912, **101**, 758).

Its active forms were at once applied to the resolution of acids with simple molecules and they speedily brought success. The first experiments, made on chlorobromomethanesulphonic acid, already gave indications that a resolution was being effected. To ensure more favourable conditions a new acid of somewhat more promising constitution, chloroiodomethanesulphonic acid, was prepared and with this compound resolution was definitely achieved. Though the possibility of its resolution was first established with *l*-hydroxyhydrindamine, it was found afterwards that resolution could also be effected—and more completely—by fractional precipitation of the very sparingly soluble brucine salt. The active acid showed a considerable molecular rotation $[M]_{5461} + 43°$ and its optical activity proved to be remarkably stable, since its aqueous solution could be boiled, even with the addition of ammonia—and indeed even heated for 2 hours at 130—150°—without loss of activity (J., 1914, **105**, 811).

Thus it was proved that a compound having a single carbon atom only in its molecule could exist in a stable optically active state. This substance contains less than 5% of carbon and there are only 9 atoms in its molecule; in the optically active anion there are but 8 atoms, only 3 more than the minimum number required for the formation of a dissymmetric carbon compound.

This discovery filled an important gap in the stereochemistry of carbon. It also removed the basis of Eiloart's suggestion that one- and two-carbon compounds were configurationally unstable. There is no theoretical justification for this suggestion. The evident reason why optically active one- and two-carbon compounds had not been obtained before was the difficulty of finding compounds suitable for resolution among the small number of molecularly dissymmetric substances in these classes.

Of the few molecularly dissymmetric compounds which they contain, some like ethylidene chlorobromide belong to types to which the usual methods of resolution are inapplicable, others like aldehyde-ammonia are unstable towards resolving agents, while others like chlorobromoacetic acid and chlorosulphoacetic acid (which, however, have subsequently been resolved) present special difficulties on account of the readiness with which they racemise, the racemisation being due, not to the kind of mobility suggested by Eiloart, but to the presence of an α-hydrogen atom rendered specially prone to prototropic change by the presence of two substituent halogen atoms, or of a halogen atom and a sulpho-group, in addition to the carboxyl.

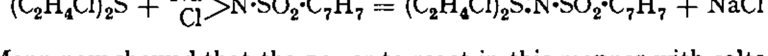
In his selection of chloroiodomethanesulphonic acid Pope's sure instinct was shown, for in the light of present knowledge it would seem that there could hardly be any compound better suited to his purpose.

Soon after this work was completed he left for Australia to attend the Australian meeting of the British Association as President of Section B (Chemistry). His presidential address, delivered in Melbourne, showed his strongly maintained interest in the Barlow–Pope theory of crystal structure. The address began with an outline of recent progress in stereochemistry, but at least two-thirds of it were devoted to the valency-volume theory. The first results of *X*-ray analysis had then just been obtained and he was able to compare the experimentally ascertained structures of diamond and rock-salt with the predictions of the theory.

During the Australian meeting war was declared and after his return to Cambridge Pope became actively engaged on chemical problems arising out of the national emergency, calling on the co-operation of most of the staff of the University Chemical Laboratory. He rendered assistance in many directions, more especially in connexion with the sources of high explosives, aerial photography and retaliation to the German use of poison gases. Many of the results of these researches were of considerable scientific interest and were published after the end of the war. Notable among them were the investigations carried out with C. S. Gibson (J., 1920, **117**, 271) on the action of sulphur chlorides on ethylene—a subject first studied by Guthrie in 1860. As a result of these researches it was shown that an almost quantitative yield of dichlorodiethyl sulphide could be obtained by the strongly exothermic reaction

$$2C_2H_4 + S_2Cl_2 = (C_2H_4Cl)_2S + S$$

Several other investigations on dichlorodiethyl sulphide were carried out in the immediate post-war period and one of these, carried out with F. G. Mann, had very interesting consequences. In connexion with the use of chloramine-T as an antidote to mustard gas it had been found by H. S. Raper that dichlorodiethyl sulphide gave a crystalline condensation product with sodium toluene-*p*-sulphonchloroamide:

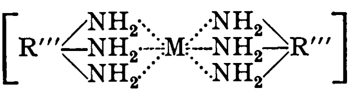


$$(C_2H_4Cl)_2S + {}^{Na}_{Cl}{>}N\cdot SO_2\cdot C_7H_7 = (C_2H_4Cl)_2S{:}N\cdot SO_2\cdot C_7H_7 + NaCl$$

Pope and Mann now showed that the power to react in this manner with salts of aromatic sulphonchloroamides was a very general property of dialkyl sulphides and for the resulting condensation products they proposed the name sulphilimine (J., 1924, **125**, 911). Pope regarded the nitrogen–sulphur link formed in this condensation as analogous to the nitrogen–carbon link in the oximes, *i.e.*, as a 4-electron bond. Kenyon and Phillips, however, subsequently resolved sulphilimines derived from unsymmetrical sulphides into optically active components, thus showing that the link was a semipolar or co-ordinate (*i.e.*, a 2-electron-) link.

After normal conditions had been restored Pope turned again to stereochemistry, entering what was for him a new province—that of the co-ordination compounds of the metals.

When an aliphatic diamine co-ordinates with a 6-co-ordinating metal, the full number of isomers required by an octahedral configuration of the complex can in many cases be obtained. Pope proposed to extend the development of this subject by studying the co-ordination compounds of the aliphatic triamines. Since compounds of the annexed type should exist in three stereoisomeric forms, of which one should be resolvable into optically active enantiomorphs, this seemed to offer a rich field for investigation and its experimental exploration was undertaken with the assistance of F. G. Mann. The expected isomerism could not, however, be realised. The first trials were made with the simplest triamine, triaminopropane,

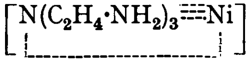


$$\mathrm{NH_2\cdot CH_2\cdot CH(NH_2)\cdot CH_2\cdot NH_2},$$

and several cobaltic and rhodium derivatives of the type $[\mathrm{M.trp_2}]\mathrm{X_3}$ were prepared, but none could be obtained in more than one form (*Proc. Roy. Soc.*, 1925, *A*, **107**, 80).

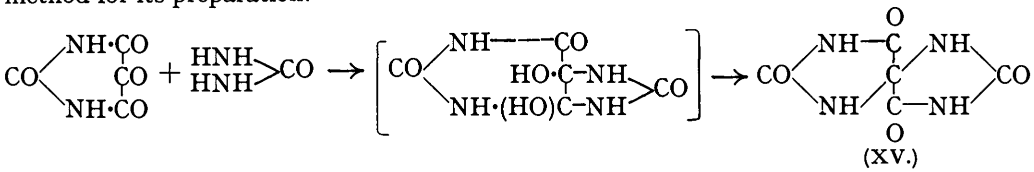
Triaminotriethylamine $\mathrm{N(CH_2\cdot CH_2\cdot NH_2)_3}$ was then examined (*Proc. Roy. Soc.*, 1925, *A*, **109**, 444). Since tertiary bases like triethylamine do not form metallic co-ordination compounds, it seemed probable that only the three amino-groups would co-ordinate so that this comparatively accessible base could be used for the study of triple co-ordination. Actually, however, all four nitrogen atoms proved able to co-ordinate, and with metals capable of 6-co-ordination compounds of the types $[\mathrm{Ni_2\,tren_3}]\mathrm{X_4}$ and $[\mathrm{Cl_2Pt\,tren}]\mathrm{X_2}$ were formed, whilst with 4-co-ordinating metals compounds like $[\mathrm{Ni\,tren}]\mathrm{SO_4}$ and $[\mathrm{Pd\,tren}]\mathrm{I_2}$ resulted. Although it would appear that the complex $[\mathrm{Ni_2\,tren_3}]^{\mathrm{IV}}$ must necessarily be dissymmetric, it could not be resolved, possibly, as Pope and Mann suggested, on account of its rapid racemisation.

The analogous base triaminotripropylamine, $\mathrm{N(CH_2\cdot CH_2\cdot CH_2\cdot NH_2)_3}$, was also synthesised and was likewise found to co-ordinate as a tetramine, giving compounds with nickel of the type $[\mathrm{Ni\,trpn}]\mathrm{X_2}$ (J., 1926, 489).

Whilst the primary object of the work thus could not be attained, various points of interest in connexion with co-ordination emerged from it. One of these concerns the configuration of the 4-co-ordinated nickel atom. Triaminotriethylamine was found to yield the nickel derivative  $\left[\mathrm{N(C_2H_4\cdot NH_2)_3 \equiv Ni}\right]\mathrm{SO_4}$, for which the simple molecular weight was established (J., 1926, 482). If the nickel valencies have the normal planar arrangement, the production of this compound clearly entails great intramolecular strain, but if they are tetrahedrally arranged, it would be strainless. A knowledge of its actual configuration is therefore much to be desired.

Another point of interest concerns the manner in which triaminopropane co-ordinates with platinic chloride (J., 1927, 1224). Interaction of the triamine with hydrochloroplatinic acid yields a product containing in its molecule 5 atoms of chlorine, of which one is ionic. It is therefore of the type $\mathrm{Cl_4Pt{<}(NH_2)_2C_3H_5\cdot NH_3Cl}$, derived from the electrically neutral diamminotetrachloroplatinum $[\mathrm{(NH_3)_2PtCl_4}]$. The relation between the two amino-groups co-ordinating with the platinum was established by showing that the compound was resolvable into optically active enantiomorphs. This proved that the co-ordination takes place unsymmetrically, *i.e.*, that α- and β-groups co-ordinate with the platinum and the γ-amino-group with the proton,  $\mathrm{Cl_4Pt}{<}\begin{matrix}\mathrm{NH_2\cdot CH\cdot CH_2\cdot NH_3Cl}\\ \mathrm{NH_2\cdot CH_2}\end{matrix}$. Thus of the two possible structures which might result from the co-ordination—the 5-ring and the 6-ring—the former is in fact produced. This accords with the conclusion to be drawn from a consideration of the relevant atomic radii and intervalency angles. The authors described this as the first recorded case of a carbon atom owing its asymmetry to the operation of auxiliary valencies.

Pope then returned to the stereochemistry of centroasymmetric substances and started investigations which led to the discovery of two particularly elegant examples of optically active compounds of the spirocyclic class. The first of these was *spiro*-5 : 5-dihydantoin (XV). *spiro*-Dihydantoins were obtained long before their constitution became known. Trimethyl*spiro*dihydantoin was encountered by Emil Fischer in 1882 in his classical investigation on caffeine : it was his hypocaffeine. He had mistaken its nature, regarding it as a 7-carbon- instead of, as it actually was, an 8-carbon-compound. Later he obtained also the tetramethyl derivative but did not discover its constitution, naming it oxytetramethyluric acid. The true nature of these compounds was first recognised by H. Biltz after his discovery of the uric acid glycols. He saw that they were spirocyclic compounds formed through intermediary unstable uric acid glycols by an intramolecular change resembling the pinacone transformation. He confirmed this view by synthesising the parent compound from urea and alloxan, thus at the same time providing a convenient method for its preparation.

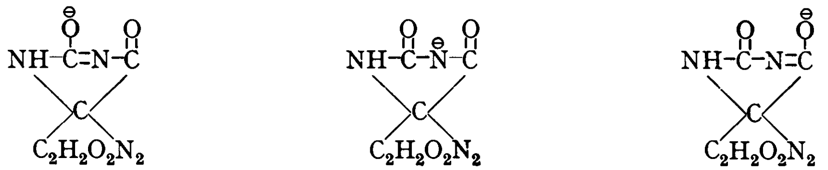


(XV.)

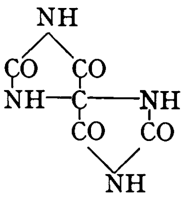
Pope's attention was attracted to this substance as a centroasymmetric compound of particularly simple constitution and he perceived that it would be sufficiently acidic to form salts with alkaloids. With J. B. Whitworth (*Proc. Roy. Soc.*, 1931, *A*, **134**, 357) he showed that it could be in fact resolved with brucine with surprising readiness, the hot alcoholic solution of the di-brucine salt depositing the *l*-form nearly quantitatively as monobrucine salt on cooling, whilst the mother-liquor deposited the *d*-form as dibrucine salt on standing. It may well be that this substance, having not more than one exocyclic atom on any ring-member, is the simplest centroasymmetric spirocyclic compound that will ever be obtained in optically active forms.

In view of the tautomeric possibilities associated with the presence of –CO·NH–· groupings the precise structure of the dihydantoin is not easily established and the interest attaching to its optical activity depends on both rings being similarly constituted, for otherwise an ordinary asymmetric carbon atom would be present. There can, however, be little doubt that the compound actually has the lactam structure (XV) and Pope and Whitworth (*Proc. Roy. Soc.*, 1936, *A*, **155**, 1) saw confirmation of this in the close relation which they found between its rotatory dispersion and that of its tetramethyl derivative formed by the action of diazomethane on the active dihydantoin, the ratio of the molecular rotations of the two compounds being almost constant over the range of wave-lengths examined. (The methyl groups in the tetramethyl derivative are known to be on the nitrogen atoms.)

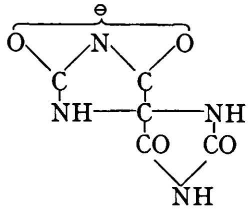
When the *d*-dihydantoin is dissolved in aqueous sodium hydroxide (1 mol.), the rotatory power falls to roughly one half. The addition of a second molecular proportion of sodium hydroxide produces a further fall in the rotation, the solution then becoming lævorotatory. Pope and Whitworth considered that these changes of rotatory power indicated passage to tautomeric enolic forms. The molecular species whose rotations are observed under these conditions are, however, the univalent and bivalent anions and these would now be regarded as resonance hybrids, the normal state of the univalent ion corresponding with resonance between the three structures



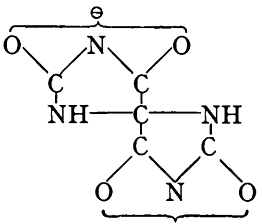
whilst in the bivalent ion such resonance would occur in both rings. The relation between structure and rotatory power $[\alpha]_{5461}$ in these substances in aqueous solution is as follows:



+112°

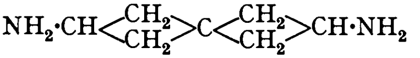


+59°



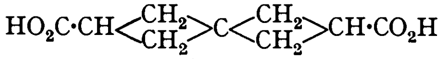
−6°

The second of the two spirocyclic compounds resolved was diamino*spirocyclo*heptane (XVI). Many years previously, immediately after completing the work on methyl*cyclo*hexylideneacetic acid, Pope and Read had made experiments on the resolution of the *spirocyclo*heptanedicarboxylic acid (XVII) obtained by Fecht in 1907 from pentaerythritol.



$\mathrm{NH_2{\cdot}CH{<}^{CH_2}_{CH_2}{>}C{<}^{CH_2}_{CH_2}{>}CH{\cdot}NH_2}$

(XVI.)



$\mathrm{HO_2C{\cdot}CH{<}^{CH_2}_{CH_2}{>}C{<}^{CH_2}_{CH_2}{>}CH{\cdot}CO_2H}$

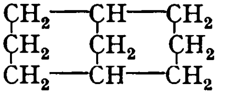
(XVII.)

Just as methyl*cyclo*hexylideneacetic acid could be regarded as derived from a disubstituted allene by the expansion of one double bond into an alicyclic ring, this acid might be considered to be derived by the expansion of both the allene double bonds into *cyclo*butane rings.

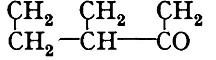
Pope and Read obtained products showing some optical activity, but the rotatory power observed was so small that the results were not published. Twenty years later (in 1931) Backer and Schurink published an account of the resolution of this acid in which the molecular rotation recorded ($[M]_D$ + 1·9° in ether) was of the same order as that which Pope and Read had observed. Pope then perceived that the diamine corresponding to (XVII) was likely to provide more favourable material for demonstrating the dissymmetry of this molecular type. Accordingly, with S. E. Janson (*Chem. and Ind.*, 1932, 316) he replaced the carboxyl groups in Fecht's acid by amino-groups, using K. F. Schmidt's newly patented method of treatment with azoimide in concentrated sulphuric acid solution. The new base thus obtained could be readily resolved by means of camphor-β-sulphonic acid into enantiomorphous forms of considerable optical activity (the hydrochloride had $[M]_{4358}$ ± 30° in aqueous solution), a result which gave Pope much satisfaction.

On account of the rigidity and the simplicity of its molecule this compound is well adapted for the application of mathematical theories of optical rotatory power and it was so employed by Born (*Proc. Roy. Soc.*, 1935, *A*, **150**, 84). The close relationship in constitution between diamino*spirocyclo*heptane and *spirocyclo*heptanedicarboxylic acid together with the tendency of enantiomorphous molecules to crystallise together to form racemates might suggest that the optically active base would form a considerably less soluble salt with the acid of unlike than with that of like configuration, so that the active base would be specially effective in resolving the *dl*-acid. This was, however, not so; the acid proved to be non-resolvable by the active base.

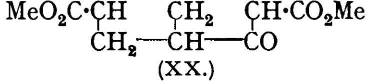
The last research which Pope undertook was an investigation of derivatives of *bicyclo*-[1 : 3 : 3]nonane (XVIII), some of which, if they could be prepared, would be of considerable stereochemical interest. The diketone (XIX) represents a type of molecular



(XVIII.)



(XIX.)



(XX.)

dissymmetry not yet realised and the hydrocarbon itself is of interest since its nine carbon atoms should be capable of assuming an arrangement identical with a section of the crystal lattice of diamond. The work was begun with the assistance of Janson and the crystalline methyl ester (XX) was obtained in an optically active form, but Janson left to take up another appointment and the investigation was never completed.

Of the great body of work which Pope accomplished, nearly the whole was thus concerned in one way or another with molecular configuration, opening up new fields of stereochemistry and enriching others. His discoveries of optically active compounds of nitrogen, sulphur, selenium and tin, and his pioneer work on centroasymmetric substances will always remain landmarks in the history of the science.

In his Melbourne address he depicted stereochemical investigation as an artistic pursuit —demanding of its followers originality of conception, intuitive choice of material, and practical sense—and in this scientific artistry he was himself a master unsurpassed.

W. H. MILLS.

(I am indebted to Professor F. S. Kipping and to Professor John Read for information which has been of great assistance in the preparation of this account of Pope's work.

W. H. M.)