OBITUARY NOTICES.

PERCY CORLETT AUSTIN.

1879—1950.

PERCY CORLETT AUSTIN was born at Darlington on January 4th, 1879. He was educated at the Royal Grammar School, Newcastle-on-Tyne, and awarded the Dale leaving scholarship in 1898. He became an Exhibitioner and Scholar of Emmanuel College, Cambridge, and there he read for the Natural Science Tripos, receiving an honours degree. After leaving Cambridge he carried out research for two years under Dr. Julius Schmidt at the Technischer Hochschule in Berlin, where he studied the chemistry of the nitrosates and nitrosochlorides derived from trimethylethylene. In January 1904 he was appointed research assistant to Professor A. Senier in Galway. There he worked mainly on the acridines, studying the addition of halogens and alkylmagnesium halides. Also he prepared various new and complex cyclic derivatives related to acridines. This work was carried out before the acridines attained their present importance through the discovery of the antiseptic properties of acriflavine and the special value of " Atebrin " and other acridine drugs in medicine, and, no doubt, it has been of service to numerous subsequent workers in this field. From 1907 to 1909 he held an 1851 Exhibition Research Scholarship and continued his researches at University College, London, and the Sorbonne, Paris. In 1909 he became lecturer in Organic Chemistry at University College, Reading, where he found time to work on the interaction of silver nitrate and potassium persulphate.

In 1913 Austin succeeded T. M. Lowry as lecturer in chemistry at the Westminster Training College, and, apart from an interruption of 3½ years during the war, he continued in this post until 1930. During this period he collaborated with T. M. Lowry in work on the rotatory dispersion of tartaric acid and the tartrates and was associated with him in the Bakerian lecture delivered in 1921. The work was published later in the *Philosophical Transactions* of the Royal Society. These substances possess anomalous dispersion, their rotation over part of the spectrum decreasing with decreasing wave-length and even changing in sign. Their rotation is also exceptionally sensitive to concentration and to the nature of the solvent. Lowry and Austin showed that the dispersion of these compounds could be represented very accurately by a two-term Drude equation, one term being positive and the other negative. This and other work showed that the rotatory dispersion of organic compounds can be classified as simple (requiring only one term of the Drude equation) or complex (requiring two or more terms). This proved much more satisfactory than the classification into normal and anomalous dispersion formerly employed. The positive and negative terms in the equations for tartaric acid and the tartrates were identified with the presence of two forms of these substances existing in equilibrium and differing only in the intramolecular arrangement of the hydrogen bonds. Austin's special contribution to this problem was to show that, if the relative positions of the two hydroxyl groups, or of the two carboxyl groups, or of both, were fixed by ring formation the dispersion changed from complex to simple, the rotation becoming comparatively insensitive to concentration and change of solvent at the same time. This effect could be achieved in part by the addition of excess of boric acid which partially fixed the hydroxyl groups, but the second term was not eliminated entirely. However, the formation of cyclic methylene derivatives eliminated the second term completely. The methylene diether of tartaric acid (the cyclic formal) was found to possess a high negative rotation and simple dispersion, while dimethylene tartrate (the dicyclic ether ester) possesses a high positive rotation and simple dispersion. Furthermore the dispersion of cyclic diacetyl tartaric anhydride is simple, but the ring is easily opened by hydrolysis with one molecule of water and the dispersion then becomes complex. Thus the existence of two forms possessing rotations opposite in sign and different in dispersion, which leads to complex and sometimes to anomalous dispersion, depends in some manner on the free rotation of the optically active polar groups.

During the 1914—1918 war Austin was chief chemist at H.M. Factory at Sutton Oak under the Ministry of Munitions and later at the National Filling Factory at Hereford. In September 1930 he was appointed Head of the Department of Chemistry at the Technical College, Paisley, and he held this appointment until his retirement in 1944. In addition to his research he collaborated with Professor Lowry in writing Part IV of Donnington's Class Book of Chemistry, and shortly before his retirement he edited and revised Cohen's " Theoretical Chemistry."

Austin married Muriel Carrier in 1911 and had one son. Both survive him. He possessed very great patience in developing techniques with which to achieve his objectives and his many students have cause to be grateful to him for that same quality applied to his teaching. He laid great emphasis on scientific honesty in laboratory work, and was a good literary critic taking great care that the writings of his friends and students should be clear and precise. He possessed a lively sense of humour and was the friendliest and most approachable of men. Austin died on November 3rd, 1950, and will be remembered with affection by many who owe much to his training and guidance.

E. E. Walker.

WALTER NORMAN HAWORTH.

1883—1950.

The death of Sir Norman Haworth on 19th March 1950 removed from our midst a most distinguished organic chemist whose strong and vigorous personality had a profound influence on scientific research and education. The family to which he belonged was well known and highly respected in the north-west of England, where it had been represented in the course of several generations by a succession of business and professional men, notably lawyers and churchmen. Walter Norman Haworth, the second son and fourth child of Thomas and Hannah Haworth, was born at Chorley, in the county of Lancaster, on 19th March 1883. His father was manager of Ryland's factory in that town and after attending the local school up to the age of fourteen, Walter Norman joined his father at Ryland's where he began to learn the trade of linoleum design and manufacture. The work required a knowledge of the use of dyestuffs and in later life Haworth was wont to attribute to this early training his first interest in chemistry and that instinct for business-like methods which remained with him throughout his life.

It soon became clear that these activities, strenuous as they were, could never satisfy the intellectual powers of the young man, and before long Haworth found means to continue his education by taking lessons from a private tutor in the neighbouring town of Preston. Despite active discouragement from his family and from friends he persisted in his studies, being fired by an ambition to pass the Entrance Examination of the University of Manchester. He did so in 1903, no mean feat in the circumstances and an indication of the brilliant intellectual powers which were ripe for development. He then entered the University of Manchester and became a pupil of W. H. Perkin, junior, who was at that time head of the Chemistry Department and at the height of his powers as leader of one of the major schools of research in the country. Haworth was described by his teachers as being a quiet, serious, and hard-working student. He made steady progress through the University curriculum and gained a First-Class Honours in Chemistry in 1906. At this stage his intention was to take a position in chemical industry after a period of research work in the Manchester laboratories. But other things were in store for him. Three fruitful years of research with Perkin were followed by the award of an 1851 Exhibition Scholarship, which he elected to hold at Göttingen in Wallach's laboratory. His experience and ability enabled him to gain the doctor's degree after only one year of study and for the second year of his Scholarship he returned to Manchester, where he continued work on the terpene group. He now had the status of Research Fellow, and in 1911, at the end of the minimum time permissible, he was awarded the D.Sc. degree of the University of Manchester.

Early in 1911 he moved to the Imperial College of Science and Technology in South Kensington as Senior Demonstrator in Chemistry under Sir Edward Thorpe. During this period, besides gaining experience in teaching and continuing vigorously with research problems, he occupied his spare time in visiting the London museums. As the result of this he acquired an astonishing knowledge of pictures, carpets, furnishings, and antique furniture.

All this, however, is to be regarded as a period of preparation during which his special powers were gradually maturing. The event which finally moulded and shaped his scientific career came in 1912 when he was appointed to a lectureship (later a readership) in chemistry in the United College of the University of St. Andrews. Here he came into contact with the new developments in carbohydrate chemistry which had been initiated by Purdie and vigorously developed by Purdie and Irvine. At long last a way appeared to be opening up for the exploration of the unknown territory of the structural chemistry of the sugars. The research laboratory in St. Andrews was an exciting and stimulating place, with Irvine as director and Purdie, although retired, still a frequent visitor and a potent influence. The importance and interest of the problems were clear and Haworth, realizing that it was impossible to do justice simultaneously to two important fields of research, gradually relinquished work on the terpenes and concentrated more and more on the carbohydrates. During this period came the development of the method of methylation of hydroxyl groups by means of methyl sulphate and aqueous alkali. Within a short time, however, the grave events of the 1914—1918 war put an end to academic research and the St. Andrews laboratories were hurriedly organized for urgent work on the production of fine chemicals and drugs. Haworth took a notable part in this and by force of personality and skilful distribution of tasks he succeeded in obtaining regular yields of the precious materials from teams of workers, many of whom had never previously seen a test-tube. Here, as in later years, Haworth's presence in the laboratory, calm, confident, somewhat austere, outwardly imperturbable as he made a round of visits to the individual workers, unmistakably inspired the feeling that the particular problem in hand not only must, but could and would be solved.

The year 1919 brought a rapid change from war-time conditions, with a return to academic research and laboratories full to overflowing with undergraduate and postgraduate students. Structural work in the carbohydrate group was renewed with vigour, Haworth's special concern being with the disaccharides, sucrose, lactose, maltose, cellobiose, and with the trisaccharide, raffinose. As his research students quickly realized Haworth put intense effort and immense energy into the problems on which he was working, and they were expected to follow suit. In addition, however, he found time to take a full part in the pleasant social life of St. Andrews, made many friends, played tennis, and took especial pleasure in exploring the wilder and less accessible parts of the Highlands of Scotland, sometimes on foot and sometimes by motor-cycle.

It was clear to all who knew him that promotion to a chair was sure to come and it was no surprise when he was called in 1920 to Armstrong College (now King's College), Newcastle-upon-Tyne, in the University of Durham, as Professor of Organic Chemistry in succession to Samuel Smiles who had moved to King's College, London. In the following year Phillips Bedson retired and Haworth succeeded him as Head of the Chemistry Department in Armstrong College. During this period problems of accommodation for the swollen student population and for a growing research school took up much time and involved much reorganization of the laboratories. Nevertheless, the work on the oligosaccharides continued steadily and a start was made on the study of the sugar carbonates, with the result that by the end of 1922 the carbohydrate school at Newcastle was well established and was attracting an increasing number of postgraduate workers. During the early part of his stay at Armstrong College, Haworth lived in Hatfield College, Durham, making many friends in both Durham and Newcastle and doing much to promote cordial relationships between the two divisions of the University. He was largely responsible for the design and equipment of the science laboratories which were built in Durham in the early part of the decade. In 1922 he married Violet Chilton Dobbie, daughter of the late Sir James Dobbie, LL.D., F.R.S. She and their two sons, James and David, survive him. Professor and Mrs. Haworth set up house in the pleasant district of Gosforth on the edge of the Town Moor to the north of Newcastle. Here the design and cultivation of a garden began to be an absorbing interest and visitors to the house were received with a kindly, gracious, and friendly hospitality which made each visit a memorable event.

At this period much thought had to be given to the design of a new chemistry department for Armstrong College, but before this could become effective events had taken place which resulted in 1925 in Haworth's move to Birmingham as Mason Professor of Chemistry in succession to Gilbert Morgan. Haworth was thereby placed at the head of a large and active school of chemistry housed in a spacious modern building on the Edgbaston site of the University. The move involved comparatively little dislocation in the research effort. A strong nucleus of postgraduate workers moved with him to Birmingham, where the research tradition had long been established and Haworth was able to watch with satisfaction the rapid growth of the carbohydrate school in both numbers and influence. From this time onwards an increasing flow of postgraduate workers from other countries was attracted to the Birmingham laboratories to gain experience of research in sugar chemistry under his direction.

The countryside surrounding Birmingham offers a plentiful choice of pleasant residential districts, and the Haworths secured a delightful house and garden at Berkswell with a history dating from Elizabethan times. Its situation in the very heart of the country some thirteen miles east of the city provided an ideal setting for the hospitality they so generously offered alike to friends and colleagues in this country and to the numerous scientists from abroad who came to visit the research laboratories.

Not long after Haworth's arrival in Birmingham an exchange of staff was arranged with the

University of Basel as the result of which Professor F. Fichter gave a course of lectures in Birmingham and Haworth paid a long visit to Switzerland. He was received with enthusiasm and during his stay abroad he lectured to the Swiss Chemical Society at Neuchâtel (April, 1928) and the Société Chimique de France at Mulhouse (February, 1928).

Another event which had important consequences was his attendance at the Tenth Conference of the International Union of Chemistry at Liége in September 1930. Carbohydrate chemistry was one of the main subjects for discussion and Haworth had been invited to give an account of ring structures in the mono-, di-, and poly-saccharides. The conference was highly successful and was memorable for Haworth because it was here that he first met C. S. Hudson, whose work he had long admired. Two years later he was invited by the German Chemical Society to deliver a comprehensive discourse on structural features in the carbohydrate group. The lecture which he had most carefully prepared was given in German before a crowded meeting of the Society in Berlin in February 1932 and was received with enthusiastic applause.

The route from the University to Berkswell unfortunately involved an awkward motor journey through several miles of busy streets and after some years Haworth began to find the driving unduly tiring. In 1933, therefore, he decided to move to a district within easier range of Edgbaston and, assisted by his architect brother, Philip Haworth, he designed and built a house at Barnt Green on the slopes of the Lickey Hills overlooking the Worcestershire plain. In design and equipment every modern device making for comfort and ease of working was incorporated, but was combined most happily with dignity of proportion and taste in decoration and furnishing. The grounds, originally bare fields, were one of Howarth's greatest delights and interests. Laid out largely with flowering shrubs and trees set in expanses of lawn they presented in a very few years a prospect of great beauty, seen to its best advantage from the main windows of the house against the background of the distant Malvern Hills.

This knowledge of architecture and building was used to good purpose when a major building problem at the University required his attention. For some years it had been clear that the Chemistry Department at Edgbaston needed expansion and apart from this much of the elementary teaching was still being conducted in temporary laboratories which had already seen many years of service. A generous gift by A. E. Hills provided the necessary funds and in due course the new building, constructed on the most modern lines for teaching and research in organic chemistry, was opened by the President of the Royal Society, Sir Frederick Gowland Hopkins, in 1937.

For many years now Haworth had been living at too high an intensity and shortly after this a breakdown in health occurred which for some time gave cause for anxiety, but a period of rest restored his strength and when the Second World War broke out he was ready to take a strenuous and highly responsible part in work on the chemical side of the atomic energy project.

For Haworth, as for so many others, the end of the war brought little relief from the pressure of work and responsibilities. The reorganization of the laboratories for peace-time work and the rapid increase in the student population of the University provided wellnigh insuperable problems of staffing and accommodation and, in addition, the call on the services of the senior members of the University for extra-mural duties remained almost as stringent as during the war. At this period, together with many other commitments, Haworth held the Chairmanship of the Chemical Research Board of the Department of Scientific and Industrial Research, and in this task he had to face the difficult problems which arose in the course of the transition from a war-time to a peace-time programme of work at the Chemical Research Laboratory, Teddington.

He had been interested from the beginning in the publication of " Advances in Carbohydrate Chemistry " which was designed to be a medium for the provision of frequent reviews of important topics in sugar chemistry and he was the British member of the Executive Committee which was responsible for the preparation of the first volume (1945). A year later he undertook an extensive and physically exhausting tour in the United States of American and Canada, in the course of which he visited many research centres, attended the Starch Round Table at Estes Park, Colorado, and lectured to the American Chemical Society. He was received everywhere with acclamation and enjoyed especially the renewal of personal contact with C. S. Hudson.

In 1948, while still at the height of his powers as a scientist and administrator, he reached the age of sixty-five, and at the end of September he retired from his post as Mason Professor of Chemistry and Director of the Chemistry Department which he had guided with such distinction for the previous twenty-three years. The severance of the ties with Birmingham University affected him strongly, but it was a source of satisfaction to him to feel that the school of carbohydrate research in Birmingham would continue under the leadership of one of his pupils

(Professor Maurice Stacey, F.R.S.), and that active centres of carbohydrate research directed by others of his former pupils were established in many universities, including Edinburgh (Dr. E. G. V. Percival and the writer), Bangor (Professor S. Peat, F.R.S.), Bristol (Dr. J. K. N. Jones), and Minnesota (Professor F. Smith). It was characteristic of him that when his many former students and colleagues at Birmingham expressed a wish to give him some token of their esteem and good wishes on the occasion of his retirement, he chose an album containing the photographs of all those who had worked in the research laboratories at Birmingham from 1925 onwards. This was prepared and was presented to him on 1st June 1949 in the presence of a large company.

Retirement, however, brought little relaxation of effort. His advice continued to be sought and he still served on numerous boards and committees, attendance at which frequently involved him in much travelling. He was invited to represent the Royal Society at the Seventh Pacific Science Congress which was held in New Zealand in February 1949. The Congress itself extended over some three weeks, and in addition to attendance at these meetings Sir Norman and Lady Haworth visited many university centres in Australia and New Zealand. He gave a series of lectures in Sydney, Adelaide, and Melbourne, and at the invitation of the Vice-Chancellor he visited the National University at Canberra. This tour in New Zealand and Australia gave him special pleasure. He was delighted with the mental vigour and vitality he encountered and it is said that young Australian and New Zealand chemists derived great inspiration from his visits to their laboratories. In every respect this tour, whilst perhaps too strenuous for a man of his age, was a great success.

After the return from Australia less than a year remained for him. There was no hint of any slackening in his activity and his interest in carbohydrate chemistry remained undiminished. Only a few days before his death he attended, as Chairman, a Chemical Society Committee on Carbohydrate Nomenclature, when he appeared to be in excellent health and spirits and conducted the meeting with his customary zest and precision. Lady Haworth and he then spent a few days in Somerset with their younger son, and returned to their home at Barnt Green on Saturday, 18th March. There had been no warning of any trouble but shortly after their return his heart failed and the end came within a few hours, peacefully and without pain or suffering.

Haworth's reputation as a leading worker in sugar chemistry was securely established by the time he moved to Birmingham and the record of the next twenty-five years showed how much can be accomplished by single-minded devotion to the elucidation of important but extremely difficult problems by a team of workers provided with the most modern equipment. Recognition of his great work and the award of honours by British and Foreign Societies and Academies came to him in a continuous flow throughout this period. He was elected a Fellow of the Royal Society in 1928; he received the Longstaff Medal of the Chemical Society jointly with Sir James Irvine in 1933, the Davy Medal of the Royal Society in 1934, and the same Society's Royal Medal in 1942. In 1935 he was President of Section B (Chemistry) on the occasion of the meeting of the British Association for the Advancement of Science at Norwich. He was the first British organic chemist to be awarded a Nobel Prize, an honour which he shared in 1937 with Professor P. Karrer for work on carbohydrates and on vitamin-C. He was an honorary graduate of many universities, including Cambridge (Sc.D.), Queen's University, Belfast (D.Sc.), Oslo (D.Sc.), and Zürich (D.Sc.). Amongst the recognitions which he appreciated most highly was the honorary LL.D. degree which was conferred on him by his own University of Manchester in 1947. Many societies and academies accorded him honorary membership (Haarlem, Brussels, Munich, Vienna, Finland, Dublin, and the Swiss Chemical Society). He served as President of the Chemical Society during the difficult years 1944—1946, and was Vice-President of the Royal Society (1947). In the University of Birmingham he held the onerous office of Dean of the Faculty of Science for some years and was Vice-Principal (for a time Acting-Principal) for the period 1947—1948. It was a source of deep gratification to his many friends and colleagues when in 1947 he received the honour of Knighthood in recognition of his work.

Of his services to science through active membership of Boards, Committees, and Councils it is impossible to write in detail, but reference may be made to the part he played in building up the Rubber Producers' Research Association, his Chairmanship of the Chemical Panel which dealt with atomic energy research during the Second World War, his work for the Colonial Products Research Council, and his Chairmanship of the Chemical Research Board of the Department of Scientific and Industrial Research. But these activities, formidable as they were in volume and responsibility, by no means complete the story of his energetic life. Haworth never spared himself in his attention to the minutest details of the running of his department. He was meticulous in the delivery of lectures to undergraduate students and in the organization of the practical classes. He was always seeking for improved methods of teaching and was never afraid of experimenting with the two aims of stimulating the interest of the student and providing him with a sound knowledge of the fundamentals of his subject. In lectures to student and to more mature audiences he was a master of clear and dignified expression, possessing an insight which enabled him to select the really important points and to give a sound exposition of an astonishing number of these in the course of a fifty minutes' lecture. His writings reveal a similar polished lucidity and compression, shown alike in his classical book " The Constitution of the Sugars " and in his scientific papers and reports.

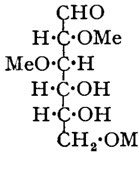
Great as were his achievements and his influence in the world of science, he will live in the memory of those who knew him even more deeply for other aspects of character and personality. Foremost amongst these must be placed the kindliness, sympathetic understanding, and thoughtfulness for others, which he possessed in such marked degree. By nature he was reserved and reticent almost to a fault about himself and his own affairs and his innumerable acts of kindness were carefully hidden, becoming known only by chance to any but the recipients. All who knew him valued his wise counsel and admired the uncompromising straightforwardness of his dealings, and his loyalty to those who worked with him. He was a man of wide interests. He travelled extensively and had friends in all parts of the world. He had a deep knowledge of the classics of English literature and his retentive memory enabled him to choose with singular felicity quotations with which he illustrated his speeches and lectures. Throughout his life he was interested in painting and when he visited a foreign city he invariably spent some time in the museums and art galleries, the points which concerned him most being the design and beauty of a picture considered as a whole rather than the technical details. Despite this width of interests he had few hobbies, for the good reason that he found the main activities of his life too absorbing to leave time for them. Yet it was not the case that he was always serious and, his outward reserve completely forgotten, he was happiest and most at ease on informal occasions and in the family circle.

In the direction of his work in the University similar qualities were evident. His reserve tended on first acquaintance to give an impression of aloofness, but the essential friendliness very soon became evident. In the conduct of his affairs he never courted popularity and he expected those associated with him to work with the single-minded intensity of purpose which was so characteristic of his own attitude. Yet he took a keen personal interest in the welfare and activities of all the members, past and present, of his laboratory. Perhaps his most striking attribute, and one of the main reasons for his success, was a capacity for inspired leadership which created in his colleagues and research workers a passionate enthusiasm for the tasks which had been assigned to them and a determination to complete them successfully despite all difficulties. It has been given to few men to possess this characteristic so markedly and to combine with it the ability to visualize and carry through to completion in all its details a great plan of research without digressions on irrelevant side issues. His vision was directed always towards the big and important problems in carbohydrate chemistry with the ultimate object of the correlation of structure with biological function, and in following his work it is interesting to see how steadily this aim was maintained. It is significant, too, that when a second chair of chemistry was founded in the University of Birmingham it was in organic chemistry with bias towards the biological side. Yet he could not have transformed so completely the field in which he worked unless he had combined with this width of vision, a capacity for recognizing and choosing the right techniques for the solution of the day to day problems. By training he was a classical organic chemist of the older school—experience which all through his career stood him in good stead—but he was also amongst the first of the newer school in recognizing that the problems in which he was interested required a combination of the resources of modern chemistry, physics, and biology for their resolution. He saw to it that every method which could be of assistance to them was made available for the research workers in his department. The laboratory at Birmingham was one of the first in the country to have at its disposal a fully-equipped department for organic micro-analysis, which very soon served as a training centre for others who wished to use this invaluable technique. His recognition of the value of X-ray investigations led to the setting up of a crystallographic laboratory which under E. G. Cox (now Professor of Chemistry at Leeds) became one of the main centres of X-ray structural investigation in the country. Full use was made of osmotic-pressure measurements, absorption spectra, conductivity measurements, optical rotatory dispersion in the visible and ultra-violet regions and, especially during Haworth's later years, when the trend of the work became more biological, all the resources of the techniques of bacteriology and biochemistry were made available. This was accomplished largely through his wise choice in the making of appointments to the staff of the department and through it he succeeded in building up a school of research comprising many independent workers each developing his own special interest, yet together forming a most powerful group for attacking those difficult and complicated problems which now confront investigators in the field of carbohydrate chemistry.

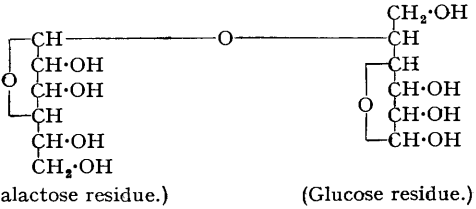
More than 300 communications on the chemistry of the carbohydrates were published from Haworth's laboratories during the period of some 30 years ending in 1948 and the discoveries they record were of fundamental importance in the development of the subject. It is clearly impossible to summarize these in a brief article and the most that can be attempted is to direct attention to some of the major achievements. Fortunately, Haworth has himself provided a series of general summaries which describe the various stages in the progress of his work. These include his book " The Constitution of Sugars " (1929), the lecture to the German Chemical Society (*Ber.*, 1932, **65**, *A*, 43), the Presidential Address to Section B of the British Association (1935), the Bakerian Lecture before the Royal Society (*Proc. Roy. Soc.*, 1946, *A*, **186**, 1), and his two Presidential Addresses to the Chemical Society (*J.*, 1946, 543; 1947, 582).

Haworth's earliest researches (1908—1914) were in the terpene group, his first publication being with Perkin under the title " Experiments on the Synthesis of the Terpenes." This was followed by work on derivatives of *cyclo*hexylidene-4-acetic acid and *cyclo*pentaneacetic acid. He carried out experiments with Perkin and Wallach on derivatives of menthane and sylvestrene and with Perkin on the synthesis of (+)- and (—)-sylvestrene. He had already begun to work independently and papers were published on the condensation of ketones and aldehydes with the sodium derivative of ethyl cyanoacetate, and on cantharene and other hydrocarbons related to the terpenes. This work was carried out at Manchester, Göttingen, and London (Imperial College) and was continued for a time at St. Andrews, but the last of the series was published in 1914. Haworth had by that time come under the influence of the St. Andrews school of carbohydrate chemistry and he decided to concentrate his efforts on carbohydrate problems. Early in 1915 there appeared an account of his new method of preparing the methyl ethers of sugars by the use of methyl sulphate and alkali. This had a profound effect on structural work in the sugar group and is still a standard procedure applicable alike to monosaccharides and to complex polysaccharides. Haworth undertook the study of the structure of the disaccharides, concerning which little was known with certainty except that the two monosaccharide residues were united by loss of a molecule of water. The new developments in sugar chemistry arising from the work of Purdie and Irvine offered at long last a method for solving these problems and for bringing some degree of order into the unexplored field of oligosaccharide and polysaccharide chemistry. The first step was the preparation of the fully methylated derivatives of the disaccharides, which were then subjected to hydrolysis by aqueous acid. Lactose, for example (Haworth and Leitch, *J.*, 1918, **113**, 188), gave an octamethyl derivative, which on hydrolysis yielded normal tetramethyl galactose, which had been obtained previously in the course of Irvine's pioneer work, together with 2 : 3 : 6-trimethyl glucose, the structure of which had been established by Denham. Octamethyl cellobiose (Haworth and Hirst, *J.*, 1921, **119**, 193) gave 2 : 3 : 6-trimethyl glucose and normal tetramethyl glucose, and octamethyl maltose yielded normal tetramethyl glucose and a trimethyl glucose which was finally identified as the 2 : 3 : 6-derivative, but was at first thought to be the 2 : 3 : 4-variety. Sucrose (1916 onwards) was troublesome from the start. Its octamethyl derivative gave on hydrolysis normal tetramethyl glucose and a labile form of tetramethyl fructose which was soon recognized as being related in structure to Fischer's " γ "-methylfructoside, but the nature of the ring system present in this sugar proved to be a formidable task the resolution of which required many years of patient work.

Nevertheless, considerable insight into the structures of the disaccharides was obtained in this way and it became possible to advance for them formulæ of the type shown below :



2 : 3 : 6-Trimethyl glucose.

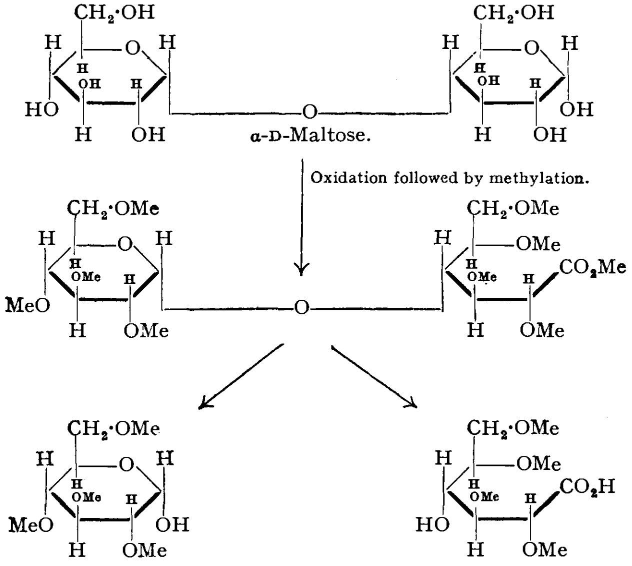


(Galactose residue.) (Glucose residue.)

Lactose.

These were, however, premature in that no sure proof had yet been given of the nature of the ring system present in normal sugars, and in 1923 when the present writer applied an oxidative technique to the solution of this problem it was found that normal methylxyloside contained a six-membered amylene oxide ring instead of the five-membered ring structure which had hitherto been generally accepted. A full examination of the nature of the ring structure of the simple sugars became necessary and the work of Haworth and the Birmingham school on the elucidation of these problems will be considered later. It was clear also that a new approach to the disaccharide problem had become necessary when the normal sugars were shown to contain six-membered rings. It was not merely a question of change of ring, but a fundamental difficulty had arisen since the isolation of a 2 : 3 : 6-trimethyl hexose left open two possibilities, namely, a 1 : 4-oxide ring with linkage through $C_{(5)}$ or a 1 : 5-oxide ring with linkage through $C_{(4)}$. The problem was solved (with Peat, *J.*, 1926, 3094) by an ingenious development of the methylation method, which may be illustrated by its application to maltose. The sugar was first oxidized by bromine water to maltobionic acid, which on methylation gave methyl octamethyl maltobionate. On hydrolysis the latter substance was split into two fragments, 2 : 3 : 4 : 6-tetramethyl glucose and 2 : 3 : 5 : 6-tetramethyl gluconic acid. The structures of both these substances were known with certainty and the new observations, taken in conjunction with the isolation of 2 : 3 : 6-trimethyl glucose in the earlier work, established unambiguously that the disaccharide linkage was between $C_{(1)}$ of one glucose residue and $C_{(4)}$ of the other. Maltose is therefore 4-α-D-glucopyranosyl-D-glucopyranose.

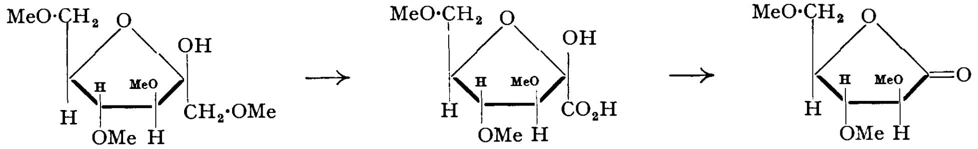
By means of similar series of experiments the structures of lactose (4-β-D-galactopyranosyl-D-glucopyranose) and cellobiose (4-β-D-glucopyranosyl-D-glucopyranose) were definitely established, and by suitable modifications of the procedure structures were assigned to melibiose (6-α-D-galactopyranosyl-D-glucopyranose) and gentiobiose (6-β-D-glucopyranosyl-D-glucopyranose). The structure of the fructose residue in sucrose remained undecided for several years. The key substance was the tetramethyl "γ"-fructose which appears as one of the hydrolysis products of octamethyl sucrose, but can be isolated most readily by hydrolysis of the heptamethyl derivative of the sugar. The proof of the presence of a pyranose ring in normal tetramethyl fructose eliminated a six-membered ring structure but still left open structures based on 1 : 2-, 1 : 3-, or 1 : 4-oxide rings, with the last as the most probable. Finally, proof of the furanose structure was obtained in the following way (with Avery and Hirst, *J.*, 1927, 2308). Gentle oxidation of the labile form of tetramethyl fructose (I) with nitric acid gave 3 : 4 : 6-trimethyl 2-ketogluconic acid (II), and on further oxidation with permanganic acid the keto-acid was degraded to 2 : 3 : 5-trimethyl D-arabonic acid, identified as its crystalline lactone (III). The nature of both ring systems in sucrose was then known, and, when cognisance of other evidence was taken, the structure α-D-glucopyranos-yl-β-D-fructofuranoside (IV) could be put forward for this most important of disaccharides. Once the structure of sucrose was known a combination of the results

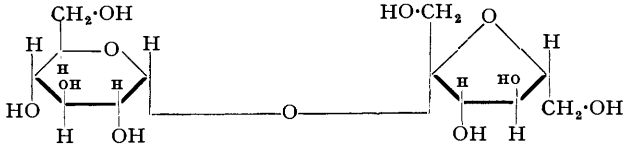


2 : 3 : 4 : 6-Tetramethyl D-glucose.

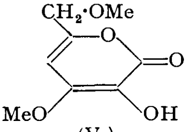
2 : 3 : 5 : 6-Tetramethyl D-gluconic acid.

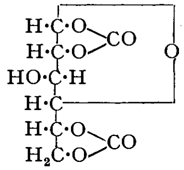
of methylation and enzymic studies revealed the detailed structure of the trisaccharide raffinose, in which an α-galactopyranose residue is linked to $C_{(6)}$ of the glucose residue in sucrose.


(I.) (II.) (III.)


(IV.) Sucrose.

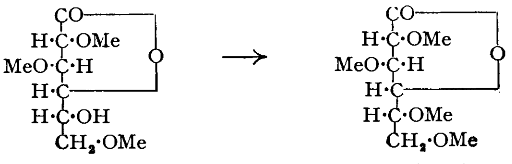
It is of interest to comment briefly on the difficulties encountered in the early work on tetramethyl fructofuranose. This reactive material gives a complex range of oxidation products, mostly liquids difficult to purify. Haworth did, however, isolate a crystalline substance with very unusual properties, to which the correct molecular formula $C_8H_{10}O_5$ was ascribed, but it is hardly surprising that this product, promising as it seemed, contributed little to the problem of sucrose structure, since it was not until eleven years later that it was recognized as being a synthetic analogue (V) of ascorbic acid which had been prepared in the course of work on the chemistry of vitamin C.

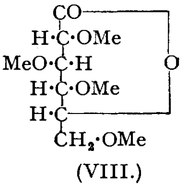

(V.)


Glucose 1 : 2-5 : 6-dicarbonate.

Simultaneously with the work on the disaccharides many other lines of investigation were being pursued in Haworth's laboratories. At Armstrong College he had commenced a study of the sugar carbonates, which can be prepared by the action of carbonyl chloride and pyridine on the sugar or sugar derivative. These proved to be of special utility in synthetic work because, being esters, they are hydrolyzed by alkalis. On the other hand they are fairly resistant to acid, in contrast with the *iso*propylidene derivatives which are not attacked by alkali but are extremely susceptible to acid hydrolysis, and as a result Haworth was able to exploit these carbonates most effectively in his work on the preparation of pure samples of the methyl glucofuranosides (see below).

A major pre-occupation of the Birmingham laboratories in the early days of Haworth's directorship was a comprehensive survey of the ring systems present in the so-called " γ " and normal forms of the methylglucosides. This work was, of course, fundamental for the whole development of sugar chemistry and without it structural determinations in the groups of the oligosaccharides and polysaccharides would have been impossible. One of the methods (*Nature*, 1925, **116**, 430) was based on a study of the lactones of the methylated aldonic acids. For instance,


(VI.) (VII.)

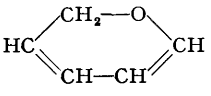

(VIII.)

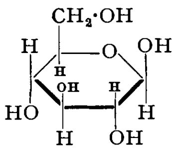
2 : 3 : 6-trimethyl glucose gives 2 : 3 : 6-trimethyl gluconic acid and the lactone (VI) of this has a rate of hydrolysis similar to those of the γ-lactones which had been used by C. S. Hudson in the formulation of his lactone rule. There is every reason therefore to suppose that it is in fact a γ- or 1 : 4-lactone. On methylation this lactone yields an equally stable tetramethyl gluconolactone

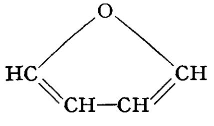
(VII), to which again the 1 : 4-structure is to be ascribed and the methyl groups must occupy positions 2, 3, 5, and 6. Now this lactone is obtained by oxidising the so-called "γ"-tetramethyl glucose derived from Fischer's labile "γ"-methylglucoside, which must therefore possess a 1 : 4-oxide ring structure. On the other hand, normal tetramethyl glucose which is obtainable by methylating 2 : 3 : 6-trimethyl glucose, yields on oxidation an entirely different tetramethyl gluconolactone (VIII), characterized by the extreme rapidity of its hydrolysis in aqueous solution. It followed that normal tetramethyl glucose must have a six-membered oxide ring and by implication this must apply also to normal α- and β-methylglucosides, results which were also established by direct application of the present writer's degradative oxidation method.

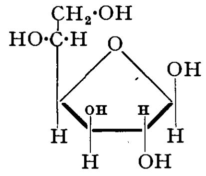
What followed can best be described in Haworth's own words, taken from his Presidential Address to Section B of the British Association in Norwich (1935). " The experimental work of the succeeding two years (*i.e.*, 1925—1927) made it possible, with the aid of colleagues and pupils, to establish the broad generalization that all normal sugars higher in the series than tetroses are constructed on the basis of the six-atom skeleton model which can be regarded now as the unit of the complex carbohydrates such as cellulose, starch, and many others. This simple model assumes the character of a sugar as soon as it is clothed with hydrogen atoms and hydroxyl groups.

" This generalization, published in 1927, had presented itself as a strong probability from the moment it was seen that the representative sugar occurring in Nature, glucose, conformed to this structural type. The experimental basis for the whole of the preliminary work was strengthened and supported by the systematic study of the sugar lactones carried out between the years 1924 and 1927. In the latter year there appeared a paper on the formulation of normal and γ-sugars as derivatives of pyran and furan, and the suggestion of a new nomenclature. The normal sugar types can all be given a standard structure recognizable under the name of a pyranose. The labile or γ-sugars, which had hitherto been but little investigated, were shown to be ascribable to the parent form of furan and therefore recognizable under a nomenclature describing them as a furanose type."

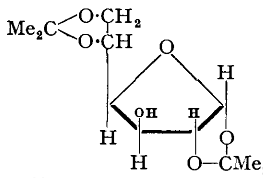

Pyran.

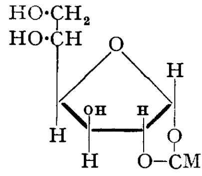

β-Glucopyranose.

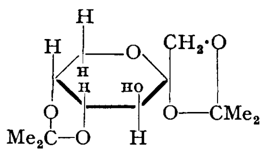

Furan.

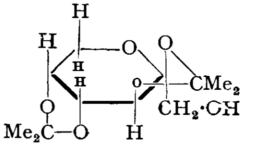

β-Glucofuranose.

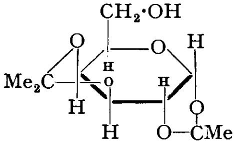
Once these fundamental structural features had been determined the way was open for structural investigations covering every aspect of carbohydrate chemistry. By use of the methylation method the structures of the *iso*propylidene derivatives of the sugars were elucidated and it appeared that with the free sugars the ring system adjusted itself during the reaction so that *cis*-hydroxyl groups on contiguous carbon atoms became available for condensation with acetone. Examples are given in the accompanying formulæ which depict di*iso*propylidene glucose (IX), the corresponding mono-derivative (X) (furanose structures), α-di-

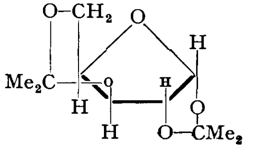

Di*iso*propylidene glucose.
(IX.)


*iso*Propylidene glucose.
(X.)


α-Di*iso*propylidene fructose.
(XI.)

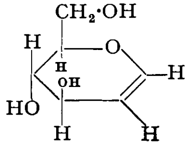

β-Di*iso*propylidene fructose.
(XII.)

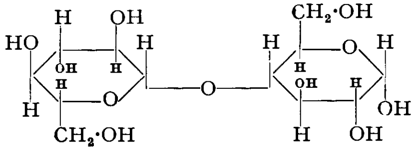

Di*iso*propylidene galactose.
(XIII.)

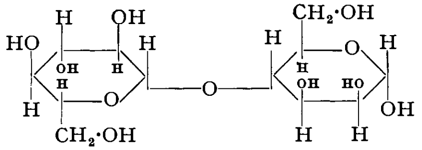

Di*iso*propylidene xylose.
(XIV.)

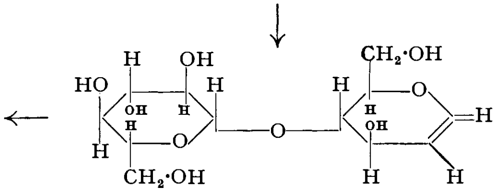
*iso*propylidene fructose (XI), β-di*iso*propylidene fructose (XII), and di*iso*propylidene galactose (XIII) (pyranose structures). The guiding principle is the formation of strainless ring systems and two further examples of this are 2 : 3-5 : 6-di*iso*propylidene mannose (furanose structure with free reducing group) and di*iso*propylidene xylose (XIV) where the second molecule of acetone condenses with the hydroxyl on $C_{(3)}$ and $C_{(5)}$ of the xylofuranose molecule with the forma- of a strainless six-membered ring.

Structural work on the glucals was carried out in the Birmingham laboratories, glucal, for example, being shown to have the pyranose structure depicted in (XV). This interest in glycals had important consequences and enabled Haworth and his colleagues to resolve a difficulty which at one time appeared to threaten the very foundations of structure assignment in the sugar group. According to Hudson's iso-rotation rules the molecular rotations of the α- and the β-form of a sugar can be written as $A + B$ and $-A + B$ respectively, where A refers to the contribution of the reducing carbon atom and B to that of the rest of the molecule. The difference between the molecular rotations should therefore be $2A$, and should be independant of the sugar. For several sugars, including, for example, glucose, galactose, and xylose, this is almost exactly true and the value of A is approximately 8500. On the other hand the rotations of α- and β-mannose do not follow the rule and Hudson put forward the hypothesis that this was because the α- and the β-form of mannose possessed different ring structures. The numerical data were such that by assuming a furanose structure for normal α-methylmannoside an apparently self-consistent scheme of sugar structures could be advanced which enabled correct predictions to be made of the rotations of substances which were unknown at the time but were subsequently prepared. But according to the chemical evidence α-methylmannoside had a pyranose structure and it followed that either the methylation procedure or the iso-rotation rules must be at fault. The issue was settled by Haworth in a characteristically direct and simple way. All methods of attack were in agreement in assigning to cellobiose the structure (XVI) in which $C_{(4)}$ of the reducing glucose residue is linked to $C_{(1)}$ of the second residue.

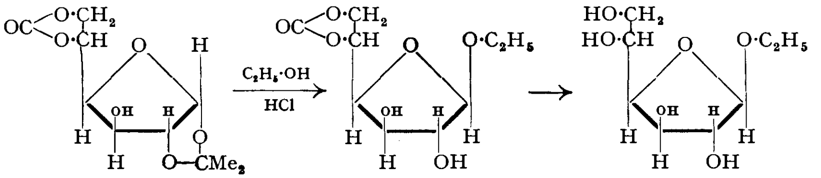

(XV.)


Cellobiose. (XVI.)

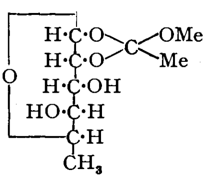

4-β-Glucosyl-α-mannose.


Cellobial.

Cellobiose cannot therefore give furanose derivatives and if the H and OH on $C_{(2)}$ of the cellobiose could be interchanged the resulting disaccharide would be a derivative of mannose which again could not react in the furanose form. This substance would therefore provide a crucial test, and means to carry it out were provided by the conversion of



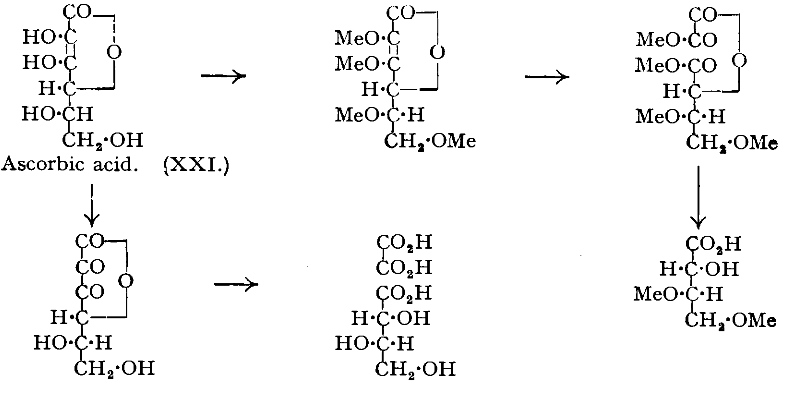
(XVII.) (XVIII.) (XIX.)


(XX.)

cellobial into 4-β-glucosylmannose by the action of perbenzoic acid. The rotations of the α- and the β-forms of 4-β-glucosylmannose and of 4-β-galactosylmannose (from lactal) gave the same value for A (*ca.* 4000) as did mannose. Only one ring structure, namely the pyranose form, being possible in 4-glucosylmannose and in 4-galactosylmannose, it followed immediately that the rotational data provided no evidence for the presence of different rings in the α- and the β-form of mannose itself and that the structural edifice built on the assumption was invalid. In a series of comprehensive papers Haworth and his collaborators proceeded to show that the rotations of sugars in which the second and the third carbon atom carry *cis*-hydroxyl groups (mannose, rhamnose) follow different numerical rules from those in which the groups are in the *trans*-position (glucose, galactose), and that the prediction of correct rotation values depended on fortuitous regularities which appear in the series of differences between the *A* values for the glucose series, the *A* values for the mannose series, and the *B* values for the pyranose and furanose varieties of the sugars (*J.*, 1930, 2615 and following papers).

Another fundamental problem which was studied at this period (1929—1932) was the preparation in a pure condition of the α- and the β-forms of methylglycofuranosides. By the usual method of preparation (methyl-alcoholic hydrogen chloride in the cold) a non-crystalline and inseparable mixture of the two forms is obtained. To obtain the pure isomers Haworth made use of the properties of the sugar carbonates. As an example the preparation of the ethylglucofuranosides will be given. 1 : 2-*iso*Propylidene glucose (X) was converted into the 5 : 6-carbonate (XVII). The latter on treatment with ethanolic hydrogen chloride gave crystalline β-ethylglucofuranoside 5 : 6-carbonate (XVIII), from which crystalline ethyl-β-glucofuranoside (XIX) was obtained by alkaline hydrolysis. By introducing a stage of acetylation, separation of the α-form of the 2 : 3-diacetyl derivative of the ethylglucofuranoside carbonate became possible and after alkaline hydrolysis ethyl-α-glucofuranoside was isolated in the pure crystalline state. The methylglucofuranosides were prepared in a similar way, and the 2 : 3-5 : 6-dicarbonate of mannose provided a starting point for the synthesis of α-methylmannofuranoside. Amongst other work in the glycoside group mention may be made of the determination of the pyranose structure of the mono-orthoacetyl derivatives of methyl rhamnoside (XX) and methyl mannoside, the triacetyl derivatives of which are found amongst the products obtained by the action of quinoline in the presence of methanol on acetobromo-sugars (with Bott and Hirst, *J.*, 1930, 1395).

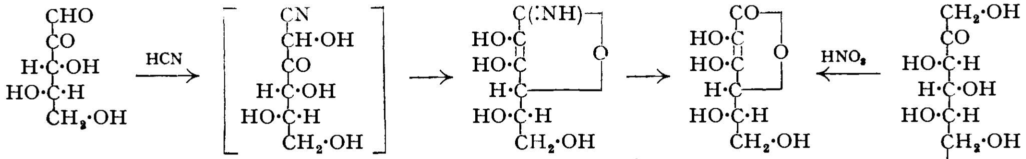
In 1932 all the resources of the Birmingham laboratories were brought into play to tackle the problems of the structure and synthesis of vitamin C. Some four years previously Szent-Györgyi had isolated from the adrenal cortex and from orange juice a highly reactive substance of formulæ $C_6H_8O_6$ which he named " hexuronic acid." Although it was suspected of having importance in biological oxidations and reductions its identity as vitamin C only became known later. With the advent of more readily accessible supplies from Hungarian paprika the writer and his colleagues at Birmingham were able to begin an intensive study of its constitution which presented many most unusual features. It was shown to be stereochemically related to L-threose and the key to its general structure was provided by the observation that although the substance itself—an enol—was acidic, its primary oxidation product was the lactone of a diketo-acid. Methylation, followed by oxidative degradation of the tetramethyl derivative, showed that ascorbic acid (the new name given to the substance by Haworth when its vitamin activity was established) had the structure (XXI).


L-Ascorbic acid. (XXI.)

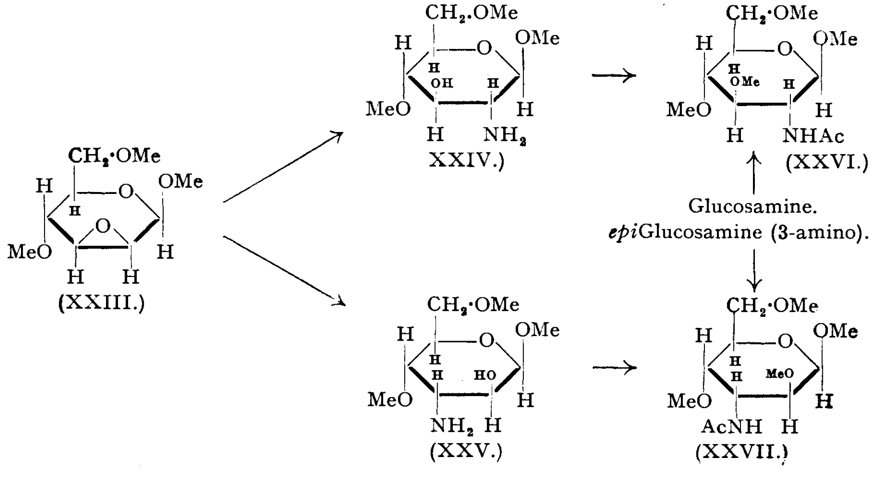
It was clear that synthesis of such a labile molecule would be a formidable task, rendered all the more difficult by the fact that the substance belonged to the relatively inaccessible L-series of sugars. But the prize, no less than the first chemical synthesis of a vitamin, was a great one, and Haworth mobilized a large team of workers, some of whom carried through pilot experiments in the D-series, while the others undertook the laborious task of preparing a sufficient quantity of L-xylosone. D-Galactose was the starting material and the successive stages were di*iso*propylidene D-galactose, di*iso*propylidene D-galacturonic acid, D-galacturonic acid, L-galactonic acid, L-galactonamide, L-lyxose, L-lyxosazone, L-xylosone. In the synthesis of L-ascorbic acid, L-xylosone was made to react with hydrogen cyanide (reagents : calcium chloride and potassium cyanide), and the intermediate reaction product was hydrolyzed, giving L-ascorbic acid identical in all respects with natural vitamin C. This spectacular result was achieved simultaneously with Reichstein's synthesis by a similar process.

Workers in many laboratories then commenced a search for physiologically active analogues and several of these were made and studied at Birmingham. In the course of this work it was discovered that the intermediate compound in the synthesis has the imino-structure (XXII) and already contains the 1 : 4-oxide ring. Here only the briefest mention can be made of the many other problems in this field which were intensively studied in Haworth's laboratories during the next few years. They included the elucidation of the extraordinarily complicated behaviour of the monomethyl and dimethyl derivatives of ascorbic acid, the synthesis of the vitamin by direct oxidation of L-sorbose with nitric acid, and the preparation of analogues of ascorbic acid having six-membered rings. The last-mentioned series of investigations led back quite unexpectedly to the problem of the structure of " γ "-fructose when one of these analogues was found to be identical with material obtained twelve years before by the oxidation of tetramethyl γ-fructose.

Yet another example of unexpected repercussions came in the course of the next year or two when a strictly chemical proof was given of the long disputed stereochemical nature of the naturally occurring D-glucosamine (Haworth, Lake, and Peat, *J.*, 1939, 371). This possibility arose as the result of a long series of investigations on the anhydro-derivatives of the sugars. Many types are known and both 3 : 6-anhydrides and anhydrides of the ethylene oxide type were studied in detail. The former were shown to be remarkable in undergoing ring changes from the pyranose to the furanose type, the 3 : 6-oxygen bridge remaining intact. The ethylene oxide anhydro-sugars are equally reactive and in most instances their opening is accompanied by Walden inversion at one of the two carbon atoms. A patient and detailed study of the phenomena accompanying the formation of these anhydro-sugars on hydrolysis of an appropriate sugar δ-toluene-*p*-sulphonate and their opening by means of sodium methoxide paved the way for the solution of the glucosamine problem.



L-Xylosone. Imino-L-ascorbic acid. (XXII.) L-Ascorbic acid. L-Sorbose.



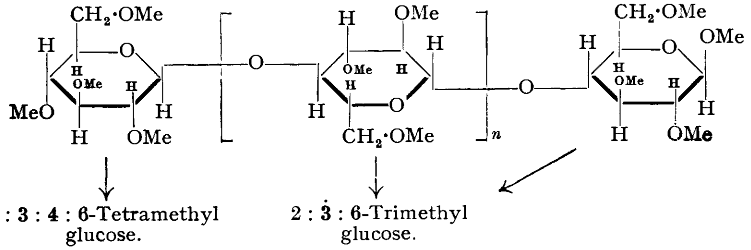
(XXIII.) XXIV.) (XXVI.) (XXV.) (XXVII.)

Glucosamine.
*epi*Glucosamine (3-amino).

The key substance for this was 2 : 3-anhydro-4 : 6-dimethyl methyl-β-D-mannoside (XXIII) the ethylene oxide ring of which is broken by sodium methoxide with the formation of the two products, 2 : 4 : 6-trimethyl methyl-β-D-glucoside and 3 : 4 : 6-trimethyl methyl-β-D-altroside. It had been proved that similar modes of scission operate when ammonia is used in place of sodium methoxide, and with this reagent the two products (which were separated by fractional crystallization of their *N*-acetyl derivatives) must be 2-amino 4 : 6-dimethyl methyl-β-D-glucoside (XXIV) and 3-amino 4 : 6-dimethyl methyl-β-D-altroside (XXV), respectively. Of these two substances the one having the amino-group on C$_{(3)}$ was recognizable because on methylation it gave 2-amino 2 : 4 : 6-trimethyl methyl-β-D-altroside, which, being a known derivative of Fischer's *epi*glucosamine, must have the amino-group on C$_{(3)}$. The other must therefore be a derivative of glucose, and its methylation product, 2-amino 3 : 4 : 6-trimethyl methyl-β-D-glucoside, was found to be identical with the product obtained by the methylation of natural glucosamine (chitosamine). Here again proof of identity was obtained by a comparison of the crystalline *N*-acetyl derivatives (XXVI and XXVII) of the two substances. Glucosamine, therefore, is really 2-amino glucose and is not a derivative of mannose. It is of interest that E. G. Cox, working in the Birmingham laboratories, furnished an independent proof of this structure as the result of *X*-ray studies of salts of glucosamine.

These examples by no means cover the full range of investigations into the chemistry of the simple sugars carried out at Birmingham. They may suffice, however, to give some idea of the scope of the work undertaken, and the reader must be referred elsewhere for accounts of other important activities, which included a comprehensive survey, sponsored by the Colonial Products Research Council, of the chemistry of sucrose and its transformation products—mannitol, sorbitol, hydroxymethylfurfuraldehyde and many others—with the object of utilizing cane sugar as the starting material for the manufacture of organic chemicals.

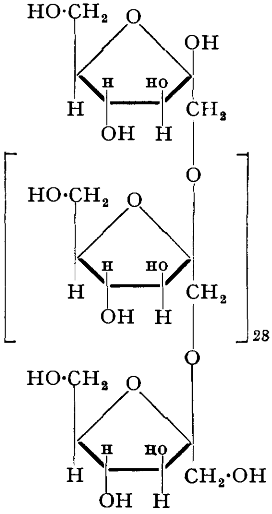
The field of polysaccharides, in which Haworth made many of his most fundamental contributions, still remains for consideration. It is probably true to say that his aim had been always towards this group of biologically important substances, and that a great part of the work in the simpler groups was regarded as a stepping-stone towards the more complicated problems of the polysaccharides. No section of carbohydrate chemistry has been more completely transformed during the last twenty-five years than this one. When Haworth's studies commenced, polysaccharides in general were regarded as substances of the little understood colloid group, probably made up of an associated assemblage of comparatively small molecules, and the idea of macromolecules in the modern sense had yet to come. One of Haworth's most brilliant contributions was his immediate recognition of the significance of the *X*-ray studies of Sponsler and Dore who had interpreted their observations on cellulose in terms of long chains of glucose residues linked throughout by normal valencies. The mode of linkage they adopted involved an ether grouping, but Haworth showed that by a simple modification the idea of the cellobiose residue as a repeating unit could be incorporated, and in 1927 at the annual meeting of the Society of Chemical Industry at Edinburgh he put forward the long chain formula for cellulose which since then has been accepted as expressing the main structural features of this polysaccharide.



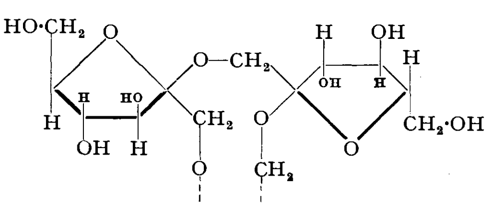
Hydrolysis of methylated cellulose.

Yet another far reaching development came in 1932 when he introduced the end-group method as a means for studying the finer details of polysaccharide structure. As applied to cellulose this involved the separation of one part of tetramethyl glucose from 200 or more parts of 2 : 3 : 6-trimethyl glucose but the analytical problem was solved by a combination of solvent extraction and fractional distillation of the mixed methylglucosides. It was established that fully methylated cellulose, as ordinarily prepared, contains one terminal group for every 100—150 glucose residues and the structure is therefore a terminated chain. This achievement was followed by a study of the cellodextrins obtained by partial hydrolysis of cellulose and by a comprehensive study of the changes in chain length which take place during the acetylation and methylation of cellulose. In its natural condition the cellulose molecule, as indicated for example by ultra-centrifuge measurements, contains more glucose residues than 150, possibly as many as 3000. The work of the Birmingham school showed that considerable shortening of the chain took place during acetylation and that the product always contained a terminal group (approximately one such group per 150 glucose residues) and similar results were obtained by direct methylation in the presence of oxygen. Much less degradation took place when methylation was conducted in nitrogen and the highly interesting result emerged that after many successive treatments of this kind a methylated derivative was obtained containing some 200 glucose residues but no end-group. Tentative explanations were advanced based on the formation of loops by the joining together of fragments of adjacent chains but the complete elucidation of this mystery has yet to be found.

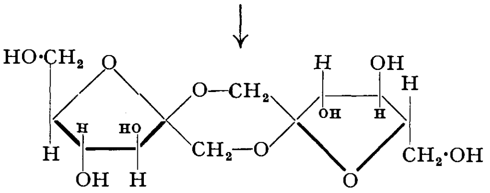
Another series of publications (1928 onwards) deals with the chemistry of inulin. This is a simpler molecule, based on 1 : 2-linked fructofuranose residues, and by application of the methylation method and end-group assay it was shown to contain approximately thirty such residues. The geometrical disposition of these provided a ready explanation of the transformation of inulin into difructose anhydrides, the structure of which was studied in detail in the Birmingham laboratories. Work was also carried out on the fructose polysaccharides present as reserve materials in meadow grass and barley leaves. These were shown to contain chains of fructofuranose units linked through $C_{(2)}$ and $C_{(6)}$.



Inulin.



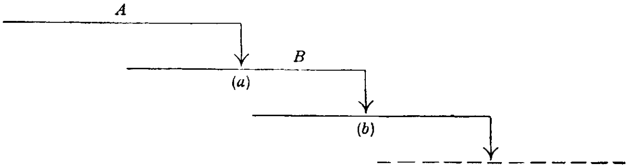
Inulin.



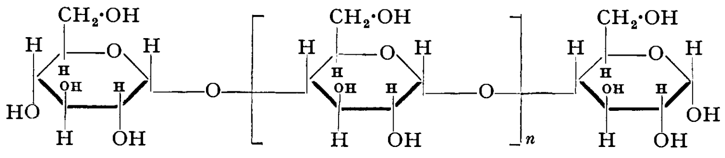
Difructose anhydride.

From 1930 onwards aspects of starch and glycogen chemistry continued to be a main feature of the work at Birmingham and in one of the earlier papers in this series a chemical proof was given (with Percival) of the presence of maltose residues in the polysaccharide. This was accomplished by a study of the controlled acetolysis of methylated starch which yielded an acetylated derivative of partially methylated maltose. This was recognized after hydrolysis, oxidation, and remethylation in the form of methyl octamethyl maltobionate. When the end-group method of investigation was applied by Plant and by Hirst to trimethyl starch the unexpected result emerged that between 4 and 5% of the glucose residues were present as terminal groups. That this was no artefact but reflected a fundamental feature of the starch molecule was proved by a careful study of the end-group assay applied to methylated starches covering a wide range of molecular weights. It was clear, therefore, that starch differed from cellulose in containing a highly branched molecular structure and the " laminated " formula was put forward (Haworth, Hirst, and Isherwood, *J.*, 1937, 578) as a diagrammatic representation of the simplest possible explanation of the observations. According to this the molecular structure consists of chains of α-1 : 4-linked glucose residues, each chain containing on the average 24 units and being joined by an ordinary glucosidic link to $C_{(6)}$ of one of the glucose units in another similar chain. This idea was applied also to glycogen in which a still higher proportion (8% for most glycogens; 6% for occasional samples of rabbit-liver glycogen) of end-groups was observed.

When it became certain from the work of Meyer, Schoch, and other investigators that most starches consist of an intimate mixture of the two polysaccharides amylose and amylopectin, separate examination of these revealed that the branched structure applied to amylopectin, whereas amylose possessed a long, unbranched chain of some 100—150 α-1 : 4-linked glucose residues. Much attention was given to the problem of preparing in a pure condition samples of the two components of various starches and new methods were elaborated including the use of the crystalline complex with thymol for the separation of amylose.

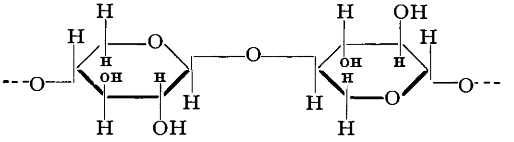


" Laminated " formula for amylopectin. *A*, *B*, etc., are unbranched chains of α-1 : 4-linked glucose residues connected at (*a*), (*b*), etc., by –G1 : 6G– linkages.

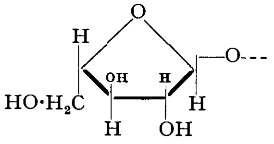


Amylose.

The discovery by Hanes of an enzyme present in potato juice capable of synthesizing a starch-like substance from glucose 1-phosphate and of transforming starch into glucose 1-phosphate opened up important new fields of enzymic studies which were actively pursued by the Birmingham research school. Hanes's synthetic starch was shown to be amylose with a chain length of about 100 glucose residues. Inquiries (with Peat) into the relationship between amylose and amylopectin in the plant led to the discovery of another enzyme, subsequently designated "Q" enzyme, which is responsible for the formation of the branched-chain system in amylopectin. By the combined action of P and Q enzymes on glucose 1-phosphate a polysaccharide closely similar to natural amylopectin was synthesized. Other aspects of the enzymic chemistry of starch also claimed attention, including the purification and mode of action of the hydrolytic enzymes designated α- and β-amylase, and a detailed study was made of the various dextrins obtained from amylose and amylopectin by enzymic degradation.



Structural unit in xylan. (XXVIII.)



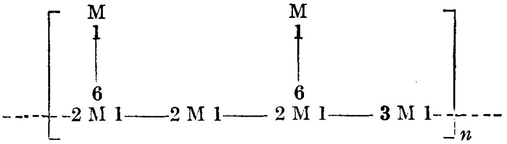
(XXIX.)

The methylation method was successfully used to determine the main structural features of many other important naturally occurring polysaccharides. An adequate summary of all this work is not practicable and only brief mention of a few items can be made here. One of the most interesting is the xylan which accompanies cellulose in esparto. This pentosan gave a dimethyl derivative which on hydrolysis yielded predominantly 2 : 3-dimethyl xylose (Haworth, Hampton, and Hirst, *J.*, **1929**, 1739). The type of structure present in the xylan molecule is therefore represented by (XXVIII), but the material is of high molecular weight and a " laminated " structure of the amylopectin type was suggested for it. Some 2 : 3 : 5-trimethyl L-arabinose was identified amongst the products of hydrolysis of the methylated pentosan (Haworth, Hirst, and Oliver, *J.*, **1934**, 1917) and it was shown that this arabinose residue disappeared on very mild treatment of the xylan with aqueous acid, leaving a true xylan in which one xylose residue in every 18 was present as an end-group (with Bywater, Hirst, and Peat, *J.*, **1937**, 1983). It seemed probable, therefore, that in natural xylan the unit chain of some 18—20 xylose residues was terminated by arabofuranose residues (XXIX). Subsequent work, however, in other laboratories renders it more likely that the arabinose residues are actually present in a separate polysaccharide, araban, and are not linked chemically to the xylan residues.

The later part of Haworth's period as Director of the Birmingham laboratories was characterized by an increasing interest in the chemistry of polysaccharides of biological importance. His laboratory and Raistrick's at the London School of Hygiene and Tropical Medicine collaborated in the study of polysaccharides synthesized by micro-organisms, and joint papers were published on the structure of mannocarolose, produced from glucose by *Penicillium Charlesii* G. Smith, varianose (*P. varians* G. Smith), galactocarolose (*P. Charlesii* G. Smith), and luteose (*P. luteum*).

$$\text{Gal 1}—\left[—\text{5 Gal 1}—\right]_x—\text{5 Gal}$$

Galactocarolose (Gal = galactofuranose residue).

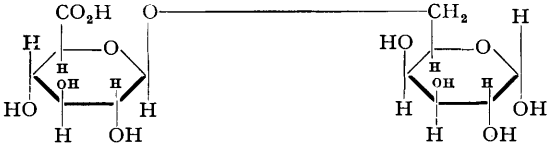


$$---\left[\begin{array}{cccc} \text{M} & & \text{M} & \\ 1 & & 1 & \\ | & & | & \\ 6 & & 6 & \\ \text{-2 M 1}— & \text{2 M 1}— & \text{2 M 1}— & \text{3 M 1-} \end{array}\right]_n---$$

Possible representation of repeating unit in yeast mannan.

Many other polysaccharides of this type were also studied in the Birmingham laboratories, including the mannan from yeast and the dextrans produced by *Leuconostoc sp.*

The chemistry of the uronic acids also received attention, and amongst the earlier researches in this group the determination of the structure of the aldobiuronic acid (XXX) derived from gum arabic is noteworthy in that this was the beginning of intensive studies of the chemistry of the pectins and plant gums, which have been continued by Haworth's colleagues in the University of Birmingham and in other universities. This aldobiuronic acid was of interest also in that it had close affinities with the highly specific polysaccharides of the pneumococcus group.



(XXX.) 6-β-D-Glucuronosyl-D-galactose from gum arabic

It was appropriate that amongst the last publications bearing Sir Norman Haworth's name were two papers (with Kent and Stacey, *J.*, 1938, 1211, 1220) on the structure of two polysaccharides which are of importance in connexion with the problems of tuberculosis. In this pioneer work the methylation procedure was again utilized to obtain some insight into the constitutions of two polysaccharides, one somatic and one lipoid-bound, produced by a human strain of *M. tuberculosis.*

This survey of Haworth's achievements in chemistry cannot be concluded without reference to the important contributions to the war effort made by himself and his colleagues in Birmingham during the period 1939—1945. When the war began the laboratories were fully occupied with work on starch, bacterial polysaccharides, plant gums, and on certain aspects of the insulin problem. Late in 1939 Howarth was approached by M. L. E. Oliphant for assistance in making available quantities of metallic uranium and its numerous derivatives. He seized upon this project with his customary vigour and the various aspects of the programme were divided amongst teams of workers in the Chemistry Department. The preparation of many pounds of highly purified uranium metal was successfully completed and a wide variety of derivatives was made in the course of an intensive search for a volatile compound. Shortly afterwards (1941) Haworth became Chairman of the British Chemical Panel concerned with the atomic energy project and the scope of the work at Birmingham was much extended by the inclusion of a comprehensive series of researches into the preparation and properties of organic fluorine compounds. All this involved a close liaison with the corresponding efforts which were in progress in the United States of America and in Canada and in the course of the following two years several of Haworth's collaborators were selected to join the staff of the newly opened experimental stations at Oak Ridge (U.S.A.) and Chalk River (Canada). At the same time a considerable team remained at Birmingham where research work went on continuously into the more fundamental aspects of the chemical problems. This work imposed a heavy strain on Haworth and his responsibilities were particularly onerous in the period from 1943 onwards, when in addition to the direction of these war projects, he took a big part in organizing the Colonial Products Research Council, under whose auspices a group of research workers was established in Birmingham in 1944 for the study of cane-sugar and starches and their transformation products. Haworth's energy and vitality at this period, when he was already over sixty years of age, appear all the more noteworthy when it is remembered that with all this he managed to combine successfully the routine duties of his Chair, the responsible and time-consuming tasks which he undertook as Dean of the Faculty of Science (1943—1946), and the many difficult problems which faced him from 1944 to 1946 as a war-time President of the Chemical Society. E. L. HIRST.

WILLIAM LOWSON.

1875—1951.

WILLIAM LOWSON died suddenly at Leeds on May 20th, 1951, at the age of 76. Born at Bridlington, he received his schooling at Bridlington Grammar School and Durham Grammar School. After leaving school he took up pharmacy and qualified as M.P.S. but, instead of continuing in this line, he attended the Yorkshire College and took the degree of B.Sc. (London) in 1900. For a short period he worked in the Government Laboratory in London, and studied for the examinations of the Institute of Chemistry, of which he became an Associate in 1901 and a Fellow in 1904. From 1901 until his death he was a Fellow of the Chemical Society. In 1903 he was appointed Demonstrator in Chemistry in the Yorkshire College, which became the University of Leeds in the following year. He took the degree of B.Sc. (Leeds) in 1905, and was promoted to Assistant Lecturer. In 1919 he was made Lecturer in Analytical Chemistry.

One of Lowson's chief interests was laboratory teaching in Inorganic and Analytical Chemistry and after a short period the organization of the courses and accessory services in all the laboratories of the Department of Inorganic Chemistry was put in his hands. As a result of his experience he published two books, " Preparations and Exercises in Inorganic Chemistry " and " Notes on Quantitative Analysis."

In the period 1925—1935 Lowson collaborated with the late Professor H. M. Dawson in an investigation of the catalysed hydrolysis of ethyl acetate, the results being published in a series of papers in the *Journal.*

During the 1914—1918 war, owing to shortage of staff, a great deal of work and responsibility in keeping the Department of Chemistry running devolved upon Lowson. Yet by working very long hours he managed to carry out, in addition, a large volume of analytical work on paints and varnishes for the War Department. When war broke out in 1939 Lowson was about to retire. As a large part of the administration and organization of the Department of Inorganic Chemistry was in his hands, his departure would have thrown a heavy burden on other members of the staff. Under the circumstances Lowson volunteered to carry on his duties for the duration of the war. This he did and enabled the Head of the Department and a team of workers to concentrate their attention on problems connected with the war.

Lowson retired at the end of the war and continued to be very active in many ways. One of his major activities was in connection with the Church of England. For over twenty years he was a Lay Reader, and week after week took services in and around Leeds. For some years he was Churchwarden of St. Chad's parish, and later was a member of the Parochial Council.

Lowson had also other and less serious enthusiasms. He was a keen and successful player of lawn tennis and played for Yorkshire in a considerable number of matches. He was the enthusiastic possessor of a motor cycle and side-car which he ran for many years, and it was with great reluctance that he exchanged it for a car when he was approaching the age of 60.

Lowson was a very conscientious man and very insistent upon accuracy in work and speech. These characteristics he tried to instil into students and others with whom he came in contact. To those who did not come up to his standards, he could make rather cutting remarks full of dry wit, but behind his words there was always a kindliness. At heart he was most kindly, and would spend any amount of time and effort to help students, members of staff, and acquaintances who were strangers to Leeds or in trouble of any kind. He was a very far-seeing man and, consequently, advice and assistance from Lowson were well worth having. He endeared himself to a very large number of students throughout his sojourn in the Chemistry Department, and when they paid visits to the Department in after years they always made a point of seeing him. He had a remarkable memory for faces and names, and a visitor whom he had not seen for twenty years would be hailed by name and reminded of the position of his bench in the laboratories.

The news of Lowson's sudden death came as a great blow to his very large circle of friends, who felt that they had sustained a great loss.

Lowson leaves a widow and a married son. J. HUME.