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EDMUND LANGLEY HIRST

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BY M. STACEY, F.R.S., AND ELIZABETH PERCIVAL

EDMUND LANGLEY HIRST was born on 21 July 1898 in Preston, Lancashire, and he died in Edinburgh on 29 October 1975. He was the elder son of the Reverend Sim Hirst and Elizabeth Hirst (née Langley). His father's family had been established in Clayton, near Bradford, Yorkshire for two or three generations. His grandfather and several uncles worked in the woollen mills while other uncles were well known as shopkeepers in Clayton. All this branch of the family were Nonconformists and strong supporters of the local Baptist church.

The Reverend Sim Hirst was a Baptist minister who was born in Clayton in 1856, the son of John Hirst a weaver and Martha Hirst. He was educated at the local school and Durham University, where he graduated B.A. He received his ministerial training at Rawdon College, near Leeds, and later gained the B.D. of St Andrews University. He was minister at Baptist churches in Stoke-on-Trent, St Andrews (three periods), Durham, Preston, Burnley and Ipswich. He died in July 1923 while preaching a sermon in Pittenweem Baptist Church.

Hirst's mother was the daughter of Joseph and Mary Langley of Liverpool where Joseph was a flour-merchant and baker. She was born in 1869 and was educated privately, showing a flair for languages. She married Sim in 1897 and survived her husband for many years, dying in March 1955. Her family came from mixed Welsh and North Country stock and had farmed land near Shap for many years. They were all Church of England in religion and his mother retained her C. of E. allegiance although attending her husband's church and acting fully as a minister's wife. Hirst was always proud of the fact that owing to tolerance and understanding on both sides, no hint of any difficulty over religious matters ever disturbed their marriage. Apart from a school teacher cousin, Hirst could not recall that any relatives had achieved academic distinction or prominence in public life. He was perhaps in consequence very proud of the achievements of his brother Sim. Sim was educated at Madras College and after being Dux of Madras College, St Andrews, took his M.A. at St Andrews University and later his B.Sc. with distinction. He did his research at Cambridge with J. J. Thomson and E. K. Rideal and after
gaining his Ph.D. joined I.C.I. Ltd at Billingham. He finally became General Manager of the Severnside project and a Director of the Agriculture Division of I.C.I. Ltd at Billingham.

Hirst's early schooling was decidedly mixed owing to the frequent ministries of his father. He attended a kindergarten school in Burnley and had lessons at home. He had a governess in Ipswich where later, 1906, he attended Ipswich Municipal Secondary School and there he felt always to be under some pressure in keeping up with other boys. He suffered a sharp setback in 1909 as a result of a severe mastoid illness.

The following year the family moved to St Andrews when in order to gain entrance to Madras College, then headed by the notable John McKenzie, Hirst had to learn, in a few months on his own, sufficient Latin to match his class III attainments in mathematics and science. His four years at Madras College were undoubtedly carefree happy ones although his science had to be sacrificed in favour of Greek!

He finished in June 1914 as Dux of the School and, after an intensive summer study, succeeded in winning a £40 Bursary and a Carnegie grant and matriculated into St Andrews University. His first year of study there covered the subjects of Latin, Greek and mathematics which he enjoyed so much that he seriously considered changing to an honours degree in classics. Quite unexpectedly however he was thrust into the world of chemistry. In the summer of 1915 volunteers were required to assist Professor (later Principal Sir James) Irvine and Dr (later Sir Norman) Haworth, Reader in Chemistry at St Andrews, in the preparation of certain fine chemicals, e.g. dulcitol and some local anaesthetics which were unobtainable in Britain; a motley team was assembled and they were taught to follow detailed preparative instructions. Hirst never forgot that his first introduction to organic chemistry involved the preparation of dimethylamine from dimethylaniline—a steep dive into aromatic chemistry which he claimed did him no harm. He continued the preparative work during his second year of study, his first real taste of carbohydrate chemistry coming from the preparation of galactose and dulcitol from lactose.

In 1917 he was called up for military service but was seconded back to St Andrews for the urgent study of mustard gas on which he conducted a pilot plant study.

In June 1918 he joined the Special Brigade of the Royal Engineers trained at Devonport and was sent to Northern France. He was demobilized as a student in February 1919 and spent the next few months in intensive study of mathematics and chemistry. He took his finals in June, gained his B.Sc. with special distinctions in chemistry, mathematics and natural philosophy and was awarded first class honours in mathematics and natural philosophy in the M.A. degree. Despite the troubled times, he had, during the undergraduate classes, gained a medal in the general Greek class, Tullis medals for mathematics in 1915 and 1916, medals for special mathematics—1915, and for junior honours mathematics—1916 and medals for ordinary chemistry in 1917 and for honours chemistry in 1918.
He decided to follow a career in chemistry and after discussion with W. N. Haworth applied for and obtained a Carnegie Research Scholarship to investigate the structure of cellobiose under Haworth's direction. He started work in the summer of 1919 and was awarded his Ph.D. in 1921. When Haworth departed for Armstrong College he worked under Professor Irvine's direction on cellulose problems and independently began the study of the ring systems in sugars, particularly xylose. At this time Irvine had become Principal and Vice-Chancellor of St Andrews and Robert Robinson (later Sir Robert, O.M., P.R.S.) was Professor of Chemistry. Robinson shortly afterwards moved to Manchester and Edmund was invited in 1923 to join his staff. He enjoyed his brief experience of working under Lapworth and Robinson where he was engaged in some depside work as well as continuing carbohydrate research. The following year he joined Haworth's staff at Newcastle and here began their famous collaboration which was to last for so many years.

Haworth moved to Birmingham in September 1925 and was not content until he brought Edmund on to his staff as lecturer in 1927 (see reference 1). His researches at Birmingham are described later. Here the two authors of this memoir became his students and have particularly happy memories of his kind thoughts for his undergraduates.

He had as fellow members of staff H. D. K. Drew, William Wardlaw, Ashley Cooper, C. E. (wee Georgie) Wood, S. R. Carter, P. Glover, W. J. Hickenbottom and F. E. Pinkard and later C. G. (Sir Gordon) Cox and C. R. Porter. All of these except Wardlaw and Pinkard had been brought into the carbohydrate research team, for which Haworth had rapidly recruited about twelve students. Hirst was given the job of Assistant Director of research together with a heavy lecturing load. He was able, however, to carry on some personal experimental work on optical rotatory dispersion with C. E. Wood.

In the 1929/30 session, because of Haworth's annoyance with some of his lecturers, Hirst gave the whole of the organic lectures to the final year! He was, however, spared all Faculty Committee and Administrative work and most of the undergraduate laboratory supervision in the huge 1st and 2nd Science, Engineering and Medical classes was done by Haworth's system of appointing Teaching Scholars and Demonstrators.

He gained his Birmingham D.Sc. in 1929 and was made Reader in the Chemistry of Natural Products in 1934 when he was also elected F.R.S.

In 1936 he was appointed to succeed Professor F. Francis in the Alfred Capper Pass Chair of Organic Chemistry at Bristol University where Professor W. E. Garner, F.R.S., was head of Department. He took with him from Birmingham J. K. N. Jones (later Professor and F.R.S.) and Geoffrey Young who formed the nucleus of his carbohydrate research team. They began work on plant gums, mucilages and starch but this was shortly to be interrupted by the war. During 1939-44 the Bristol laboratories were given over to work on explosives and Edmund and Professor Garner supervised a team of research workers—a branch of the Research Department of Woolwich. Edmund's duties involved regular visits to several ordnance factories, both manufacturing...
and filling. He served as a member of several committees of the Scientific
Advisory Council (Ministry of Supply) and of various committees set up by
the organization dealing with explosives manufacture—Ministry of Supply.
Various members of the Bristol staff were engaged in the projects which now
occupied 90% of Hirst’s time. He was also concerned with Civil Defence as
Senior Gas Adviser to the South Western Region. However, maintenance of
teaching in the Department was greatly helped by the evacuation to Bristol
of the staff and students of King’s College, London, under Professor G. M.
Bennett who with Dr Gwyn Williams took part in the research programme.
Classes were combined as far as possible.

In 1944 Hirst was invited to follow A. R. Todd (now Lord Todd, P.R.S.)
as the Sir Samuel Hall Professor of Chemistry at Manchester University, and
he took up his duties there in January 1945, together with some members of
the Bristol team in order to complete the war work. The change over from the
wartime conditions and the rapid increase in student members involved him
and Professor Michael Polanyi in considerable reorganization and the planning
of new laboratories. He also became heavily involved as Chairman of the
Research Section in the working party set up by Sir Stafford Cripps and
chaired by Sir George Schuster, to report on the cotton industry. He also
became a member of the Advisory Research Committee of the Shirley Institute.
Nevertheless, his interest in carbohydrate research was maintained and special
mention should be made of his association with J. K. N. Jones which began
at Birmingham and continued at Bristol and Manchester. This proved exceed­
ingly fruitful as is shown by the publication of some fifty joint papers in the
complex polysaccharide field. Although Jones took up a chair at Queen’s
University, Canada, their close friendship was maintained throughout the
rest of Hirst’s life.

In 1947 came a call which delighted him for his heart was ever in Scotland;
this was to Edinburgh University where Professor James Kendall had created
a second chair of chemistry—the Forbes Chair of Organic Chemistry. Here
he was to remain for 21 highly profitable (in the chemistry sense) and happy
years. When Kendall retired in 1959 Hirst took over the onerous work of Head
of the Department and this he retained until he retired. Such were his out­
standing characteristics that he commanded the unfailing support and coopera­
tion of his staff. The staunch support given by Dr (later Professor) Neil
Campbell should not be forgotten.

Hirst gave devoted service to his country throughout his career for his
presence and wise council were in great demand at all levels. He was honoured
by the award of a Coronation Medal in 1953, made C.B.E. in 1957 and Knight
Bachelor in 1964.

ReSEARCHES

Hirst’s first venture under W. N. Haworth’s direction in the carbohydrate
field at St Andrews were a logical follow up of Thomas Purdie’s pioneer use
of methyl ether protective groups and its application notably with Sir James
Irvine to attack the structure of di- and polysaccharides. W. N. Haworth had appreciated that the most urgent problem was to decide whether the ring systems in carbohydrates were, as considered to be at that time, five-membered or whether they were six-membered. Hirst discovered almost immediately that controlled oxidation of crystalline methylated sugars with nitric acid gave certain dibasic acids the nature of which could be used to decide the size of the ring.

Thus with C. B. Purves in 1923, he showed that crystalline tri-O-methyl d-xylose, on oxidation with bromine water, gave a readily hydrolysable lactone (shown to be 2,3,4-tri-O-methyl d-xylo lactone) which on oxidation with nitric acid yielded i-xy/otrimethoxy-D-glutaric acid which could only arise if the original d-xylose had a six-membered ring.

This was a dramatic discovery and this technique, together with studies on the rates of hydrolysis of lactones of carbohydrate acids (aldonic acids), then known as ‘γ and δ lactones’, was applied to determine over the next decade or more especially during their Birmingham association, the structure of all the known mono-, di-, oligo- and poly-saccharides.

The Haworth–Hirst partnership was a model of research directorship. Research fellows were unknown and 90% of the experimental work was done by research students. Haworth and Hirst would jointly decide on the topic to be undertaken by the student. Together at some time during the morning they would make their round of all the workers with Haworth doing all the talking and in the late afternoon Hirst would make a personal round quietly relieving some of the Haworth pressure on the student. One could rely on Haworth’s departure at 4 p.m. with Hirst making himself available usually until 6.30 p.m.

Reference to the list of publications will show the wide variety of ring structures settled. The writing up of papers was shared—Haworth’s pyranose and furanose terminology helping matters considerably (2).

There was no lack of ideas, one of us (M. S.) at one time having no less than eleven research topics assigned to him! Both leaders were powerful advocates of teamwork and this was seen to great advantage when speed was necessary as with certain studies of the optical rotatory power of carbohydrates and with the work on ascorbic acid. For these rush jobs research students were ordered to round off their present topics and were formed into ‘syndicates’. In 1930 a syndicate was formed to resolve a controversy which had arisen between C. S. Hudson and the Birmingham school.

From his celebrated isorotation rules Hudson claimed that he was enabled to predict the ring structures of sugars some of which were then unknown. The rotation of α- and β-mannose, however, did not fit into his rule and Hudson claimed that this was due to the fact that the α- and β-forms of mannose possessed different ring structures. When, however, a five-atom (furanose) ring structure was assumed for normal α-methyl mannoside the numerical data did fit. According to the Birmingham chemical evidence, α-methyl mannoside possessed a six-atom or pyranose structure and if Hudson was correct
then the whole of the methylation evidence was faulty. The syndicate attacked the problem via the glycals of which glucal is a typical example. Cellobial was the key compound for the formula for the disaccharide cellobiose from which it was derived was accepted by Hudson since it fitted his rules. In cellobiose and cellobial C4 of the reducing glucose residue is linked to C1 of the other glucose residue, so that cellobiose cannot give a furanose derivative. Thus if the H and OH on carbon atom 2 of the cellobiose could be interchanged the resulting disaccharide would contain a mannose derivative which could not react in the furanose form. The conversion of cellobial into 4-β-glucosido-mannose was achieved by treatment with perbenzoic acid. The rotational properties of the α- and β-forms of the 4-β-glucosido-mannose and of 4-β-galactosido-mannose (made from lactal) gave similar values to that of mannose, and since no furanose rings were present in these structures it followed immediately that the rotational data gave no evidence for the presence of different rings in α- or β-mannose so that Hudson’s theories were incorrect. Confirmation was achieved in a series of papers rapidly produced which solved many problems of carbohydrate structure and their optical rotatory power.

Haworth and Hirst put their results forward in a notable carbohydrate conference in Liège, Belgium, in September 1930 when Hudson was present. Hudson graciously accepted defeat and later wrote in his autobiography (3):

‘The new results from methylation data which Haworth and Hirst presented at that conference led me to return home with grave doubts of the validity of the views that I had advanced of the basis of my interpretations of rotatory relations. Therefore I sought to find some way by which evidence on this question could be obtained that would be independent both of methylation data and rotatory relations. The result is well known to organic chemists. By applying the periodate oxidation of Malaprade to carbohydrates of many types the workers in our laboratory were able to obtain the desired independent evidence. It confirmed the views of Haworth and Hirst in all respects.’

Work at Birmingham continued on the synthesis of furanose forms of sugars which involved quite remarkable and elegant studies of crystalline sugar carbonates. The beginnings of studies on conformation, neighbouring group reactions etc. were also appearing at this time with papers on Walden inversion, novel forms of stereo-isomerism (ortho-acetate formation) and so on as well as further pioneer work on di- and poly-saccharides.

All of this had to stop, however, in 1932 for almost the whole of the Research School was formed into yet another ‘syndicate’ to study the ‘hexuronic acid’ which Szent-Györgi had invited Haworth to investigate. This had been christened ‘God-knows’ by Szent-Györgi and was known by no other name in the laboratory though it was later to become famous as the antiscorbutic factor——vitamin C or ascorbic acid.

Hirst was greatly amused by a special visit to Birmingham by the formidable Professor H. E. Armstrong, who came to protest about the name given to this vitamin and who then wrote a letter to *Nature* saying that ‘Ascorbic’ acid was indeed a ‘Scurvy name’.
The story of the determination of the structure and the synthesis of this, the first vitamin to be synthesized, has been written up many times. The speed at which it was all achieved was due to Hirst’s initiative and inspiration to the team. During the next few years with F. Smith and J. K. N. Jones as team leaders he investigated a wide range of analogues of ascorbic acid and numerous derivatives such as the methyl ethers.

Two particular studies at Birmingham were to point the way to much of his future interests, these were his work on the carbohydrates of grass and of barley leaves and the pioneer researches on mannanuronic acid and on glucuronic and aldobionic acids from gum arabic. He eventually published 32 papers on ‘Uronic acid materials’. His last paper with Haworth was Polysaccharides part XXXVIII, on fish liver and muscle glycogens. Henceforth his interests were to be in the field of the highly complex plant gums, mucilages, pentosans, seaweed polysaccharides and some rare starches etc.

In the starch work he was ably assisted by G. T. Young in Bristol and T. G. Halsall in Manchester, while at both universities J. K. N. Jones had charge of the team engaged in all the complex plant polysaccharide studies. In these problems close contact was maintained with Fred Smith’s group in Birmingham. Despite the troubled times over 70 publications resulted from the Bristol and Manchester periods. The work was enormously speeded up by the discovery of new elegant oxidative methods and revolutionary automated chromatographic techniques.

The discoveries especially on plant gums with those of Smith revealed structures of remarkable complexity and great beauty and added considerably to new knowledge of plant chemistry. The work is adequately summarised in the book Chemistry of plant gums and mucilages by F. Smith and R. Montgomery (4).

At Edinburgh Edmund found a ready-made distinguished Assistant Director of research in the late E. G. V. Percival, who had played an important part in the ascorbic acid work so that with other able members of staff who joined his group his researches suffered no setback.

During the 20 fruitful years in Edinburgh Hirst built up a large research team in collaboration with D. M. W. Anderson, G. O. Aspinall, C. T. Greenwood, D. J. Manners, E. G. V. and Elizabeth Percival and D. A. Rees. A brief description of the wide variety of plant products investigated is given below.

**Fructans**

The structure of inulin from dahlia tubers was established as a linear structure of about 33, 2→1-linked β-D-fructofuranose residues which are terminated at the potential reducing end by a molecule of sucrose.

Studies on the levans from the grasses, Dactylis glomerata and Lolium perenne, showed them to comprise unbranched chains of 25–30 2,6-linked β-fructofuranose residues terminated at one end by fructose and at the other by a sucrose molecule. In contrast the fructan from couch grass, Triticum repens,
was shown to be a highly branched fructan with the fructofuranosyl units linked through C1, C2 and C6. The presence of 4% glucose indicated that the chains are again terminated by sucrose.

Work on the changes occurring during growth and on silage preparation demonstrated the importance of the fructans and sucrose in the making of good silage, this applied angle always being in Edmund’s plans.

**Starch and glycogen**

Studies into the fine structure of starches and glycogens from various sources involved a wide variety of enzymatic studies, and physico-chemical measurements on starch and glycogen determined the molecular size, average chain length, conformation in solution etc. Average chain lengths in samples of amyllopectin were determined by the concomitant action of \( \beta \)-amylase and pullulanase.

Similar experiments on the \( \beta \)-limit dextrans of glycogen and the measurements of the maltose and maltotriose liberated gave the degrees of branching. Differentiation between amyllopectin and glycogen was achieved from (a) measurements of limiting viscosity number, (b) the greater concentration dependence of sedimentation coefficients for amyllopectin and (c) its greater affinity for iodine.

**Hemicelluloses**

The polysaccharides that accompany cellulose in the plant cell wall consist mainly of xylans, arabinogalactans and glucomannans.

Considerable studies were carried out on xylans from cereal grains, from woody tissues and on related polysaccharides from seaweeds. Work on extracts from rye flour, from wheat, barley and oat straw, from barley husks, from maize cobs, fibre and hulls, cocksfoot grass and from esparto grass and pear cell wall revealed a family of polysaccharides. These were based on a backbone of \( \beta \)-1,4-linked xylose units with different proportions of short side chains of L-arabinofuranosyl residues linked to C3, and D-glucuronic acid and its 4-O-methyl derivative attached to C2 in the xylan backbone.

Alkali-soluble xylans from woody tissues were also examined, in particular that from beechwood which was the first investigation that allowed assignment of the complete structure to a wood xylan. This comprised approximately 70 \( \beta \)-1,4-linked xylose residues per average molecule with single 4-O-methylglucuronic acid units attached in 1,2-linkage to every tenth residue of the linear backbone. A similar xylan was isolated and characterized from Norway spruce *Picea excelsa*.

A xylan from the red seaweed, *Rhodymenia palmata*, was shown to consist of linear chains of 25% of 1,3-linked and 75% of 1,4-linked xylose residues. In contrast the xylan from the green seaweed, *Caulerpa filiformis*, consisted of residues solely in 1,3-linkage.

Arabinogalactans from various trees were also studied. From methylation and linkage analysis experiments on that from the European larch, *Larix*
decidua, E-galactan, it was deduced to be a highly branched material with a main chain of 1,3-linked galactose units and 1,6-linked residues united to the main chain at C6 and 1 in every 12 residues carrying an arabinofuranosyl residue.

Glucomannans from coniferous woods are typified by that from Sitka spruce, *Picea sitchensis*. This was shown to be made up of essentially linear β-1,4-linked chains of glucose and manno residues in apparently random distribution along the chains.

In addition with some coniferous woods, for example Scots pine galactoglucomannans, experiments have shown that the glucose occurs as single unit side chains attached to C6 of the β-1,4-linked residues in the main chain.

Coupled with these studies were those on pure mannans from ivory nut and from *Codium fragile* which were characterized as comprising chains of β-1,4-linked manno residues.

A highly branched galactoglucomannan was also separated from reindeer moss (*Cladonia alpestris*). Investigation revealed a backbone of D-glucose and D-mannose. Most of the galactose and a small proportion of the other sugars served as end groups.

Work initiated by E. G. V. Percival on glucans from Iceland moss (*Cetraria islandica*) was continued and two glucans, isolichenin and lichenin, were characterized as linear polysaccharides, comprising α-1,2-linked (3 parts) and α-1,4-linked (2 parts) glucose and β-1,3- (3 parts) and β-1,4-linked (7 parts) glucose respectively.

Foridean starch from the red seaweed, *Dilsea edulis*, was shown to resemble amylpectin, whereas the starch from a variety of green seaweeds and the unicellular alga, *Dunaliella bioculata*, contained an amyllose and an amylpectin moiety. Both materials appeared to have smaller molecular weights and less organized granules than the starches of land plants.

A water-soluble phyto-glycogen from *Zea mays* (sweet corn) was also studied.

Starch-type polysaccharides from the unicellular organisms, *Haematococcus pluvialis* and *Tetraselmis carteriiiformis*, were studied.

A glucan from the Protozoan, *Cycloposthium*, was shown to be of the amylpectin-type. In contrast the Protozoan, *Chilomonas paramecum*, grown in culture metabolizes a starch-type polysaccharide comprising both amyllose and amylopectin.

**Seaweed mucilages**

Brown seaweeds, *Phaeophyceae*

Work on the constitution of alginic acid begun in Bristol was continued. The presence of a high proportion of β-1,4-linked mannuronic acid units in the molecule was proved. The presence of 1-guluronic acid residues was confirmed and their 1,4-linkage established. The occurrence of the two acids in a single molecule was shown by partial hydrolysis of a carboxyl-reduced sample of alginic acid and the characterization of a derived mannosylgulose.
Chemical and enzymic studies of laminaran, a reserve polysaccharide of the Phaeophyceae, established it as a linear β-1,3-linked glucan of some 20 residues. It was shown that there was 2–3% of mannitol in various laminaran samples, that this terminated 75% of the chains at the potential reducing end in soluble laminaran and 46% in the insoluble form, and that the degree of branching in the former was 0.3 and in the latter 1.6 for samples from *Laminaria* and from *Fucus* spp.

A similar β-1,3-linked glucan devoid of mannitol was isolated and characterized from a mixed culture of diatoms.

The main structural features of fucoidan, a sulphated polysaccharide were shown to be chains of 1,2-linked fucopyranose units carrying half ester sulphate at C4 and branches, at C3 on every fifth unit, of terminal 4-sulphated fucose residues.

Red seaweeds, *Rhodophyceae*

Work begun with E. E. and E. G. V. Percival on red seaweed mucilages was continued in collaboration with D. A. Rees in the 1960s. The alternating 1,3- and 1,4-linkages in the galactan chains were established. λ-Carrageenan was fractionated and formulae advanced for the different fractions. Evidence that galactose 6-sulphate units in these polysaccharides can be converted quantitatively into the 3,6-anhydride, chemically by treatment with alkali or enzymatically by an extract from the seaweed was also supplied.

Green seaweeds, *Chlorophyceae*

Water-soluble complex sulphated heteropolysaccharides from a variety of genera were investigated. *Cladophora rupestris*, *Chaetomorpha* spp., *Caulerpa filiformis* and *Codium fragile* metabolize similar families of polysaccharides containing variable proportions of D-galactose and L-arabinose with less D-xylose. Extensive studies on *Cladophora* mucilage showed the presence of end group, 1,6-linked and 1,3-linked 6-sulphated galactose, 1,4/5-linked 3-sulphated arabinose, and end group and 1,4-linked xylose. In contrast *Ulva*, *Acrosiphonia* and *Enteromorpha* species mucilages contain residues of D-glucuronic acid, L-rhamnose, D-xylose and D-glucose. Evidence was obtained for the presence of sulphate ester on C2 of both rhamnose and xylose residues. On the basis of various fragmentation experiments the following sugar sequences were recognized:

\[
\text{D-GlcUA(1\rightarrow4)L-Rha 2-sulphate...D-GlcUA(1\rightarrow3)D-Xylp1...D-GlcUA(1\rightarrow4)D-Xylpl...}
\]

\[
\text{D-GlcUA(1\rightarrow2)L-Rhap(1\rightarrow3)D-GlcUA(1\rightarrow3)D-Xylp}
\]

**Exudate gums and related polysaccharides**

A considerable proportion of the research effort was devoted to these highly branched complex polysaccharides from a wide variety of sources.

Acacia gums comprise the largest single group of exudate gums and work on them by the Edinburgh school has shown that they are based on a highly
branched framework of β-D-galactopyranosyl residues. Work on gum arabic and gums from *Acacia arabica*, *A. pycnantha*, *A. nubica*, *A. nilotica* and *A. drepanolobium* has revealed that they all contain D-galactopyranosyl residues mutually joined by 1,3- and 1,6-linkages. Residues of β-D-glucuronic acid and 4-O-methyl-D-glucuronic acid, both in outer chains attached to C6 of galactose in terminal or near-terminal positions and outer chains of L-arabinofuranosyl residues, and in some cases terminal L-rhamnopyranosyl residues were shown to be a feature of these gums. Degradation studies have shown a highly ramified structure in the inner galactan core. Terminal residues of β-D-glucuronic acid in *A. arabica* and *A. nubica* gums appear to be joined (1→4) to unbranched D-galactosyl residues. In the former of these gums 57% of the polysaccharide was revealed to consist of L-arabinose mainly in the furanose form in 1,3-linkage in exterior chains.

While no unequivocal structure was advanced for these polysaccharides, formulae representing large portions of the molecules which correspond to all the established facts have been advanced.

Other polysaccharides based on a galactan core in which the 1,3-linked β-D-galactopyranosyl residues are concentrated in inner chains are found in the minor polysaccharide component of *Khaya senegalensis* gum and the gum from *Araucaria bidwillii*. Methylation and other studies in Edinburgh revealed many similarities in their structure with the *Acacia* gums. A minor component of gum tragacanth was also shown to have a galactan core with highly ramified outer chains of L-arabinofuranosyl residues.

The gums from *Anogeissus latifolia* (gum ghatti) and *A. leiocarpus* are typical acidic mannan polysaccharides and represent the first two clearly authenticated glucuronomannans. Extensive structural studies on gum ghatti established the presence of inner chains of alternate 1,4-linked β-D-glucuronic acid and 1,2-linked α-D-mannopyranose residues. Side chains of L-arabinofuranosyl residues linked at C6 to mannose and more complex side chains containing 1,3-linked β-D-galactopyranose, 1,2-, 1,3- and 1,5-linked L-arabinofuranosyl residues and end group glucuronic acid linked to C6 of D-galactose were also characteristic of this gum. *A. leiocarpus* gum has many similarities to gum ghatti but, in contrast to the latter, investigation revealed the presence of two structurally related polysaccharides. These differ from gum ghatti in that over 50% of the molecule is the glucuronomannan and most of the side chains are single L-arabinofuranosyl residues linked to C3 of mannose. There are also single D-xylopyranosyl units linked to C6 of mannose. D-Galactose is a minor component with similar linkages to those in gum ghatti.

The gum from another member of this family, *Combretum leonense*, which was studied in considerable detail, resembles the acidic polysaccharide of beech tension wood more closely than *Anogeissus* gums. It comprises chains of β-D-1,6-linked galactopyranose units carrying at C3 chains of L-arabinofuranosyl and arabinopyranosyl residues. Arabinosyl units are also attached to C4 of the acid moiety of the aldobiuronic acid, β-D-glucuronic acid (1→6) galactose, and the following tetrasaccharide branched at C4 of rhamnose: D-Galp(1→4)
Extensive studies on gums from the genus Sterculia and some from species of Khaya established the presence of variable proportions of D-galacturonic acid and L-rhamnose residues in the interior chains and in some species D-galactopyranose was also revealed in the inner chains. These gums in the natural state are partly acetylated.

Gum tragacanth and Khaya senegalensis gum provide examples of gums that contain two structurally different types of polysaccharide, whereas it was shown that Combretum leonense gum contains a continuous spectrum of related molecular species.

The major components of Khaya grandifolia, K. senegalensis and K. ivorensis gums were investigated and shown to comprise a family of closely related polysaccharides with similar constitutions but different proportions of the constituent sugars. Interior chains consist of blocks of 1,4-linked galactopyranuronic acid residues interrupted by 1,2-linked rhamnopyranose residues and with side chains of terminal 4-O-methyl a-D-glucopyranuronic acid residues linked to C4 of rhamnose in the main chains by a 1,4-linked D-galactopyranose unit. The presence of the aldobiuronic acid, 4-O-methyl-α-D-glucopyranosyluronic acid (1→4) D-galactose in a partial hydrolysate of K. grandifolia gum provided the first evidence for the presence of both D-glucuronic and D-galacturonic acids in the same polysaccharide.

In tragacanthic acid similarities to the Khaya gums emerged. Enzymic studies revealed two and three contiguous residues of 1,4-linked α-D-galacturonic acid residues, whereas partial acid hydrolysis yielded the aldobiuronic acid, α-D-galacturonic acid, linked to C2 of rhamnose. Acetolysis studies revealed a highly branched molecule with short side chains of the disaccharides, α-L-fucopyranose residues and β-D-galactopyranosyl residues each linked to C2 of xylose. These two disaccharides and also single units of xylopyranose units are present in β-linkage to C3 of the galacturonic acid chains.

Studies of Sterculia setigera, S. caudata (Brachychiton diversifolium), S. urens gums and the botanically unrelated, but structurally similar Gossypium gossypium gum have established the main features. The interior structure consists of alternate residues of D-galacturonic acid and L-rhamnose with side chains terminated by D-glucuronic acid and D-galactose. Methylation and partial hydrolysis experiments demonstrated a close structural similarity in the four gums. The main structural features can best be illustrated by the results on S. urens gum. This comprises chains of alternate 1,4-linked α-D-galacturonic acid and 1,2-linked L-rhamnopyranose residues with branches of single unit β-D-glucuronic acid at C3 of the galacturonic acid units. C4 of the rhamnose residues also carries undetermined side chains. Other structural features are 1,4-linked galacturonic acid residues attached to C4 of D-galactopyranose units and carrying D-galactopyranosyl residues at C2.

The first example of a xyloarabinan was isolated from cress seed mucilage. It was shown to contain chains of 1,5-linked α-L-arabinofuranose residues
with xylopyranose end groups. The disaccharide, α-D-xylopyranose attached to α-L-arabinofuranose residues, is joined at C3 to the main chains. A similar central core was demonstrated for mustard seed arabinan.

An acidic branched polysaccharide was also separated from the cress seed mucilage. The interior chains consisted of 1,4-linked galacturonic acid and 1,2-linked L-rhamnose residues branched at C4. The major external chains comprised the aldobiuronic acid, 4-O-methylglucuronic acid linked to C4 of D-galactopyranose. The disaccharide 4-O-α-D-xylopyranosyl-D-galactose was also present as side chains.

Work initiated by E. G. V. Percival on Plantago seed mucilages was continued after his death on the mucilage from Plantago arenaria. It was shown to be a highly branched structure containing xylose (12 pts end group, 1,4- 1,3- and 1,3,4-linked), arabinose (3 pts, arabinofuranosyl 1,3-linked and end group), galactose (1 pt end group) and galacturonic acid (1–2)L-rhamnose (1 pt).

Synthetic studies

Authentic mono-, di- and tri-methyl ethers of arabinose, xylose, fucose, fructose, mannuronic, galacturonic and glucuronic acids were synthesized. These authentic derivatives were necessary for the characterization of the methyl ethers derived from the methylated polysaccharides.

Crystalline glucosamine 6(dihydrogen phosphate) was also synthesized for the first time.

Outside interests and offices

The Royal Society

He was elected in 1934. He served on the Council during 1945–47 and 1962–64. Also as a member of the Chemistry Sectional Committee twice, once as chairman; member of Government Grant Board (Chemistry) on at least two occasions.

Lecture, Bakerian, 1959.
Medal, Davy, 1948.
Society Representative on the Court of Heriot Watt University.
Member, Royal Society Dining Club, to 1969.

The Royal Society of Edinburgh

Elected, 1948.
Vice-President, 1958–59.
President, 1959–64.
Lecture, Bruce-Preller, 1951.
Member, Royal Society of Edinburgh Dining Club.

The Royal Irish Academy

Elected Honorary Member, 1967.
The Royal Scottish Society of Arts
Elected Honorary Fellow, 1964.

The Chemical Society
Fellow, 1922.
Member of Council, 1939–42.
President, 1956–58.
Lectures, Tilden, 1940.
Hugo Muller, 1948.
C. S. Hudson Memorial, 1954.
Pedler, 1955.
Medal, Longstaff, 1958.
Member of various committees.

The Royal Institute of Chemistry
Fellow, 1934.
Member of Council, 1942–44.
Vice-President, 1967–69.
Representative in Edinburgh University.

The Society of Chemical Industry
Member, 1934.
Member of various committees and Chairman of Edinburgh Section.

Member of the following societies:
Faraday (since 1934); Biochemical (since 1935); Society of Experimental Biology; American Chemical Society; Polish Chemical Society, Honorary Member (1959); Swiss Chemical Society.

The British Association
Member since 1922.
President of Section B, Birmingham Meeting, 1950.
Council, 1964–68.

The Brewing Industry Research Foundation

The D.S.I.R.
Chairman, 1950–55, of the Chemistry Research Board. Former Member of the Students’ Committee and Chairman of the Chemistry Sub-Committee, 1950–56. Former Member of the Forest Products Research Board. Former Member of the Research Committee of the Shirley Institute.
Edmund Langley Hirst

The Institute of Seaweed Research

Member of the Board of Governors.
Chairman of the Research Committee.

Member of the following

Council of Management of the Macaulay Institute for Soil Research; Plant and Soils Committee of the Agricultural Research Council; the Blackman Committee reporting on the Natural Rubber Industry; the Scientific Advisory Council of the Ministry of Supply.

Member of the Governing body of the Hill Farming Research Organization and Chairman of its Research Committee.

Member of the Board of Governors of the Rowett Research Institute.

Member of the Board of Governors of the East of Scotland College of Agriculture and Convenor of its Appointments Committee.

Association with the Heriot Watt College and University of Strathclyde

Shortly after he went to Edinburgh Hirst was appointed University Representative of the Governing Body of the Heriot Watt College. He had already become extremely interested in technological education and relationships between industry, universities and colleges of technology.

He was very proud of this association and he derived very great pleasure and satisfaction from his long association (27 years) with the College. He found great interest in all aspects of the work of the College serving on many committees and giving great help.

Hirst was equally proud of his association with the University of Strathclyde. When an Academic Advisory Committee was appointed to advise on the transformation of the Royal Technical College into an independent university, he was invited to become Chairman of the Committee charged with the preparation of a draft charter and statutes and with advising on ordinances, regulations and academic matters generally. The drafts were accepted by the Governors of the College and forwarded to the Privy Council. The College attained full university status in the summer of 1964. He was elected to the University Court in 1965. His work for both Strathclyde and Heriot Watt gave him special satisfaction and he always spoke with pride of the pleasure he felt when each of these universities honoured him with their honorary degrees.

Hirst was also proud of the award to him of honorary degrees from the Universities of Aberdeen, Birmingham, St Andrews and Trinity College, Dublin.

He was pleased also with his election to the Fellowship of the Heriot Watt College in 1964 while his membership of the Watt Club of which he was Vice-President in 1966 and President in 1967 was a real joy.

A highlight of his Presidency was a visit with his friend Principal H. B. Nisbett to the Oslo branch of the Club where he met many former students.
Contacts with other universities

Throughout his career, Hirst was in constant demand to lecture and to act as external examiner at other universities. He once totted up the number of universities at which he had lectured—it amounted to 38 to which he added 8 of the London colleges. He was an excellent lecturer and teacher and this was reflected in his skill as an external examiner.

He often commented on the fairness of the external examinership system as it has developed in the British universities and considered that its value in maintaining standards was indeed great though not always understood by non-academics.

Personal appreciations

We have received many tributes from Edmund’s friends and include shortened versions of some of these for they do describe in the best way his interests and hobbies and bring out the warm feeling and affection we all felt for him.

Professor Wesley Cocker writes:

My wife Eleanor met Edmund for the first time in 1926 when he visited her grandparents with whom her uncle W. N. Haworth was staying. I first met him in the 1940s when he became external examiner to the University of Durham, but I did not really get to know him until I took up my present appointment in Trinity College. He was the second of our Werner Society Lecturers (1949). He and Kay, whom he had just married, stayed with us in Dublin and I was immediately attracted by his personality. After that first visit he came to Dublin often as lecturer at the Royal Dublin Society, as external examiner in Trinity College, and as recipient of the honorary doctorate in science of the University of Dublin. He had two periods as external examiner; on the first occasion he was sole examiner. He was a most thorough examiner. In the viva voce examinations he quickly put candidates at ease by his obvious kindliness and quiet manner, but they very quickly found that sloppy answers would not be tolerated. He had little sympathy with the candidate who thought that organic chemistry is a matter only of reaction mechanism. Nevertheless, many students of this College could testify to the kindness with which he handled nervous candidates at viva voce examinations.

Edmund would never travel by air if he could find a boat and/or train to take him to his destination and he had a fund of knowledge of railway routes. His many journeys to London by the East Coast mainline made him an expert on its geography. His knowledge of the line from Manchester (Piccadilly) to Euston and Manchester (Central) to St Pancras was extensive.

Edmund was a keen gardener and even during the last year of his life he spent time in his vegetable garden. In his more active days his vegetable and fruit garden was always a treat to visit. He was also a keen photographer and
he had many cameras and a most extensive set of transparencies, all carefully
documented. One of my great delights was to sit in his study seeing slides of
the shots that he took on his many visits to various parts of Scotland, which
he loved so much.

I shall always remember Edmund as a person with a great depth of chemical
insight, but more, I shall remember him as a firm friend, completely without
'side' and of the utmost integrity. I shall always remember the great kindness
he showed to his students, of whom my daughter was one.

One of us, E. P., writes:

From my student days and throughout my life Edmund was a most valued
friend and counsellor. I owe him a tremendous debt, for without his constant
help and support I could not have achieved what little success I have had in
the world of carbohydrates. To my mind his most outstanding characteristic
was his integrity, allied to kindliness and thoughtfulness for others. He was
never too busy to discuss their personal problems and difficulties with friends
and colleagues. At social gatherings he always made a point of talking to the
less important persons present and made efforts to make them feel at
home.

He never lost his interest in research. Even after he took over the 'Head of
Department' and many outside commitments his direct interest in research
continued and he made every effort to attend and take part in the monthly
meetings, which he had inaugurated at Edinburgh, of the departmental staff
engaged in carbohydrate research. These meetings consisted of discussions
of current problems and recent publications in a very wide field of carbo­
hydrate research. He would on occasion act as 'Devil's advocate' if one member
had been delegated to discuss a recent controversial publication.

His review lectures were models of their kind in which wider aspects of poly­
saccharides and their rôle in plant life were discussed. Where appropriate their
application to life in general was commented on.

He was an excellent chairman who had always carefully studied the agenda.
In his quiet way he kept a firm control of the proceedings. Although he was
careful to see that each member had an opportunity to put forward his view
he made certain that a clear decision was finally reached.

He had friends throughout the world who never failed to visit him whenever
they came to Britain. They all recall the delightful hospitality extended to
them by Sir Edmund and Lady Hirst. Throughout their married life the latter
supported him in all his undertakings. Without her help and understanding
it would have been impossible for Edmund to have undertaken the vast amount
of work he did.

In his younger days Hirst often went climbing in the Welsh mountains
and in more recent years happy days were spent hill walking. Many are the
tramps we have enjoyed together on the Pentland hills and the Border hills
near Yetholm.
Edmund Hirst was a gentleman, in the best sense of the word. He was always courteous, and showed a kindly interest in the well-being of his colleagues and associates, and in their families. He tended to be reserved and shy, especially at public functions, but in smaller groups, he could be good company; then a quiet but well developed sense of humour would be revealed. I remember him solemnly explaining to some Russian chemists visiting King’s Buildings that the cars in the car park belonged mainly to the students, and that the bicycles outside the building belonged to the staff, and included his own! He delighted in telling anecdotes about illustrious chemists—Fellows of the Royal Society, or former Presidents of the Chemical Society and the like. One of these excused himself from a meeting at Burlington House on the grounds that he had an urgent meeting elsewhere and was later seen coming out of the Windmill Theatre.

Of non-scientific activities, his real love of music and literature, particularly of pre-20th century composers and writers, was important. He possessed a surprisingly detailed knowledge of the railways of this country—he was almost a ‘walking Bradshaw’, who had travelled extensively by rail during the 1939–45 war, and regularly thereafter. Whilst most others found such journeys tedious and monotonous, he found them full of interest, and would relate some new fact or experience to his colleagues on his return.

His outside activities included golf (a relaxation perhaps rather than a serious sport), walking in the hills and gardening. He loved the peace and quiet in the countryside and hated crowds.

Sir Edmund was characterized by his sense of duty in all his commitments, teaching and professional.

As chairman of committees his homework was always done in great detail. His introduction of lecturers and votes of thanks were always models of their kind.

Although always quiet and unassuming he could be very determined. During his Presidency of the Royal Society of Edinburgh, a certain Dr ‘X’ and some Scottish Nationalists became objectionable with certain lines of questioning at a meeting. After a tolerant few minutes Hirst leapt to his feet and said ‘Dr X, I rule you out of order’ and that was that. I recall that at the end of a completely incomprehensible lecture by a visiting Japanese chemist Hirst jumped on to the platform and said ‘Thank you, Professor Y; on this occasion there will be no opportunity for questions’—the meeting was closed. He was a great friend to all his staff.

When I was an undergraduate at Birmingham, Edmund Hirst gave the main lecture course on carbohydrates, and he conveyed such interest and
enthusiasm that I asked if I could accompany him to Bristol to work for my Ph.D. At that time organic chemistry in Bristol had not been very active, and Hirst proceeded rapidly to build up a vigorous school of research. It was an exciting time to be there. Hirst would see his research students daily; he was always helpful, kindly, and patient, with a quiet sense of humour, and he inspired deep personal loyalty and affection in the whole group, which was a very happy one.

Already in 1938 he and W. E. Garner had planned to cooperate in a programme of explosives research, in preparation for the war which then seemed inevitable, and A. Carruthers and H. D. Springall came to Bristol in 1939 as the first members of an extra-mural team of the Ministry of Supply. Both Hirst and Garner became immersed in the process of establishing and coordinating academic assistance in explosives research and development, through the Scientific Advisory Council and its committee, and in this, for the duration of the war, they were tireless. The extensive travelling which was required must have been a great strain, perhaps relieved in part by Hirst's longstanding interest in railways. Not content with this contribution to the war effort, Hirst was also Senior Gas Adviser for the South-West Region.

I visited him in Edinburgh on many occasions, and there he was obviously extremely happy—a happiness which his marriage to Kay made complete. As a family, we would always call and find a welcome from the Hirsts when we were in Scotland on holiday.

From J. S. D. Bacon:

I might say that my first scientific contact with Sir Edmund came early in my career. You will see a paper in the *Journal of the Chemical Society* for 1940, page 1147, in which D. J. Bell explains why we had attempted the synthesis of 4:6-dimethyl galactose. We had this material crystallized within a few weeks, but were dismayed to discover that it did not have the properties of the substance isolated by Hirst and Jones, so we had to keep the results on ice until a letter from Professor Hirst explained the discrepancy. I do not think I met him in this period, although we travelled by road one day to Birmingham to hear his lecture about cellulose. When I did meet him I was immediately impressed by his friendly and modest attitude, and it was a pleasure to find him taking such an interest in the work of the Macaulay Institute when I arrived there in 1966.

The Council of Management met half yearly and Sir Edmund made it his practice to travel to Aberdeen on the previous evening in order to spend the time available to him before the meeting in conversation with the organic chemists and biochemists, in particular the carbohydrate chemist, the late R. B. Duff. He was very helpful to me.

I never lost altogether my sense of disbelief that Sir Edmund with all the pressures that his University and professional commitments must have put on him could remain such a good listener and show such unassertive but genuine interest in the details of our research.
The other of us (M. S.) concludes:

I enjoyed a close personal friendship with Edmund from my undergraduate days and I owe much in my own career to his wise counsel and help freely given at all times. We came very close during the tense weeks of the ascorbic acid work. When the great moment came for the taking of the first mixed melting point of synthetic and natural ascorbic acid—a crucial test in those days—I said, 'Shall we toss to decide who takes it?' 'No', he replied, 'you take it and I will sit behind you to catch you if you faint!' He afterwards confessed that he had measured the u.v. spectrum of the material and already knew that we had indeed synthesized a vitamin for the first time. It was characteristic of him to inform Professor Haworth immediately of the good news and then calmly to sit down and write up the paper!

We had many common interests especially in matters concerned with cellulose. I followed him as a member of the Forest Products Research Board and we sat together on Research Committees of the Shirley Institute. We were able to exchange ideas when he was D.S.I.R. Visitor to the Jute Industries Research Association and I acted in a similar capacity to the Paper and Packaging Research Association.

We helped jointly to establish the Advances in carbohydrate chemistry, on the Advisory Editorial Board on which he remained for the rest of his life. He served also as a member of the Editorial Board of Carbohydrate research and of the Robinson-Rodd books on the Chemistry of carbon compounds.

Together we represented the Chemical Society in founding the Anglo-American Carbohydrate Nomenclature Committee though at our first important meeting with American colleagues on a hot summer's day in New York he was missing! A message was received to say that he found it necessary to spend the afternoon under a cold shower in the hotel bedroom and that he much preferred the cool breezes of Edinburgh to the hot breath of New York! He made later visits to the U.S.A.

His home life in Weoley Hill had not been easy, but he never allowed it to interfere with his work—to quote his own words:

'In 1925 I married Beda Winifred Ramsay, daughter of Frank Ramsay of Glasgow, a close friend of my father. Prospects for the marriage were excellent but unfortunately soon after the wedding my wife was found to be suffering from an incurable progressive mental illness. There followed some extremely difficult years. By 1937 the trouble had so much increased that treatment in hospital was urgently necessary and she remained in hospital until her death some years later.

'In 1948 this marriage was dissolved and in 1949 I married Kathleen Jennie Harrison ('Kay'), H.M.I. in the Ministry of Education—daughter of Charles Lyell Harrison—a Birmingham Headmaster. This marriage has been ideally happy and for 25 years my wife has been a tower of strength to me. Very soon after coming to Edinburgh she became involved in a variety of activities—in the University, in the various Ladies' Clubs
and the Women Students' Union; in work for spastics and crippled children; for old people; a multitude of activities for the Edinburgh College of Domestic Science, now Queen Margaret College (Chairman of the Governing Body, 1971); a member of the Council of the Moray House College of Education with special interest in Halls of Residence; member of Council (Chairman, 1971) for the Edinburgh Southern Hospital Group Training School for Nurses—to all of which she has devoted tremendous interest and energy.

Edmund was so proud of Kay and together they made a fine team. We wish her good health to continue long her good works.

Apart from a connection with I.C.I. Ltd, Edmund had little time for industrial consulting work. He was particularly proud of his collaborators and former pupils many of whom have reached high positions in the academic and industrial worlds.

So many of us have cause to be grateful to him. King's Buildings can never be the same without him. All the Scottish universities and institutions, Edinburgh University in particular and the Scotland which he loved, must ever acknowledge the debt owed for the life and work of this quiet, unassuming and lovable great gentleman.

We have drawn heavily on Sir Edmund's own notes prepared for the Royal Society. We are also grateful to many friends who have helped us in the preparation of this memoir.

The photograph reproduced is by Walter Bird.

REFERENCES


BIBLIOGRAPHY


The structure of ascorbic acid. J. Soc. chem. Ind. 52, 221.
(With S. S. Zilva) Ascorbic acid as the antiscorbutic factor. Biochem. J. 27, 1271.
(With W. N. Haworth) Synthesis of ascorbic acid. J. Soc. chem. Ind. 52, 645.


1942  Recent progress in the chemistry of the pectic materials and plant gums. (Tilden Lecture.) J. chem. Soc. p. 70.


(With J. K. N. Jones) The structure of egg-plum gum. II. The hydrolysis products obtained from the methylated degraded gum. J. chem. Soc. p. 120.


Proceedings of a colloquium on 'The industrial utilisation of agricultural products and of seaweed'. Third session. Dublin: The Royal Institute of Chemistry.


Modern developments in carbohydrate chemistry. \textit{Advent Sci.} no. 26, September.


1954 (With (the late) E. G. V. Percival & Clare B. Wylam) Studies on seed mucilages. VI. The seed mucilage of Plantago arenaria. J. chem. Soc. p. 189.

(With D. J. Manners) Multiple-branching in amylopectin. Chem. and Ind. p. 224.


(With I. D. Fleming & D. J. Manners) α-1:4-glucosans. IV. A re-examination of the molecular structure of Floridean starch. J. chem. Soc. p. 2831.


Structural chemistry of plant polysaccharides with reference to their colloidal character. Verh. Kolloid-Ges. 18, 104.


(With W. Mackie & Elizabeth Percival) The water-soluble polysaccharides of *Cladophora rupestris* and of *Chaetomorpha* spp. II. The site of ester sulphate groups and the linkage between the galactose residues. *J. chem. Soc.* p. 2958.

1966 The role of sugars as energy reserves in nature. *Jl R. Soc. Arts* 114, 290.


1972 (With D. J. Manners & I. R. Rennie) α-(1→4)-d-glucans. XXI. The molecular structure of starch type polysaccharides from *Haematococcus pluvialis* and *Tetraselmis carteriformis*. *Carbohydrate Res.* 22, 5.
