

Newsletter

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Front cover pictures: upper: Wave surface model (see page 14)  
lower: From WL Bragg's paper, 1912

## Editorial

Aragonite –  $\text{CaCO}_3$  - Orthorhombic crystal which exhibits strong double refraction. Pseudo-hexagonal twins often found in Aragon, Spain. So says the Field Guide to Rocks and Minerals but what has this to do with the AGM lectures presented at Leeds University on 29<sup>th</sup> October?

It was this material which Humphrey Lloyd used in 1833 to demonstrate conical refraction which had been so surprisingly predicted by William Rowan Hamilton. As Lloyd himself said:

*'here then are two singular and unexpected consequences of the undulatory theory, not only unsupported by any phenomena hitherto noticed, but even opposed to all the analogies derived from experience'.*

By a curious piece of editorial serendipity it was also the material whose structure was defined nearly 100 years later by William Lawrence Bragg which according to Hunter\* 'broke the sound barrier of x-ray analysis' since up to 1923 as Bragg pointed out:

*'it was considered practically impossible to analyse crystals of lower symmetry than cubic, tetragonal or hexagonal'.*

But such analytical techniques were essential to the continuing development of x-ray crystallography and it was again at Leeds where great progress was made in the emergent field of molecular biology, specifically with regard to the relationship of molecular structure with gross physical properties of natural polymers, by William Astbury. Although the term 'molecular biology' was not coined until 1938 it is interesting to note that 10 years earlier he had been appointed as Lecturer in *Textile Physics* which concerned itself very much with these questions.

And many answers were forthcoming from our three speakers as well as yet more questions posed – a thoroughly enjoyable afternoon which was introduced by our host, John Lydon, with a bonus 'armchair science heritage tour of Leeds'.

*Malcolm Cooper*

\* Light is a Messenger by Graeme K Hunter - See Issue 18 for a review

## **Chairman's Report of the Group's activities (Oct 2004 – Oct 2005)**

The AGM took place in the Poynting building of the Physics Department of the University of Birmingham on Saturday, October 30<sup>th</sup> 2004. Seven committee members were present as well as a further eight ordinary members. Professor Ian Butterworth from Imperial College, London formally announced his resignation as Chairman of the group to be replaced by Professor Denis Weaire of Trinity College, Dublin. Following the earlier resignations from the committee of Dr Chris Ray and Professor Bob Chivers, we welcomed at the AGM the appointments of Dr Peter Borchers, formerly of the University of Birmingham and Mr Malcolm Cooper (now retired from the broadcasting industry). Malcolm Cooper kindly agreed to take on the role of Newsletter editor and during the year has produced the 17<sup>th</sup> edition in the Winter of 2004 and the 18<sup>th</sup> edition in the Summer of 2005.

The lecture programme, which followed had the enigmatic title “Was there life before Einstein?” but was mainly devoted to Sir Oliver Lodge and John Henry Poynting, which was highly appropriate given the venue for the meeting. Some forty people attended including many present and former staff members from the Physics Department of the University of Birmingham. Peter Rowlands spoke on ‘Sir Oliver Lodge and Relativity’, Graham Alfrey on ‘John Henry Poynting - A sketch for the future Research’, Denis Weaire on the obsession of Lodge with the spirit world and communicating with the dead and Ben Benedikz on “Lodge and Poynting – Two brief character sketches”. Reports of these lectures have appeared in the 18<sup>th</sup> edition of the Newsletter. In addition Peter Ford showed a short video film of Lodge lecturing around 1934 originally made by the Institution of Electrical Engineers.

In May of 2005, a few committee members went to Trinity College, Dublin for a committee meeting and also to have an opportunity to find out more about scientists associated with the University, in

particular, of course, Hamilton. In addition, they were treated to a performance of Carl Djerassi's play "Calculus"- the dialogue between Newton and Leibnitz over priority for the discovery of calculus. It was given in the same lecture theatre as Schrödinger gave his famous lectures on 'What is Life' in 1944.

At the committee meeting it was resolved that 1500 Euros from the group funds should help fund the book 'The Hamilton Tait Correspondence', which has been produced to mark the two hundredth anniversary of the birth of William Rowan Hamilton. A further thousand pounds was set aside to help finance the celebrations at the University of Liverpool to mark the centenary of the birth of Herbert Fröhlich, who was a Professor at Liverpool for many years.

Over the year discussions have taken place between Malcolm Cooper and Professor Jim Morgan and Dr John Lydon, both of the University of Leeds over the production of a reprint of two booklets written by Professor William Stroud in the mid 1930's - "Apologia pro Vita Mea", and 'Early Reminiscences of Barr & Stroud Rangefinders'. This was ready for distribution to the membership at the AGM held at the University of Leeds on 29<sup>th</sup> October 2005.

## **New AGM Reporting Procedure**

As you know the group's activities centre on the half-day meeting held to coincide with the AGM and the Chairman's Report was normally given to the group 12 months later. Our newsletter editor is hopeful that two issues a year can continue to be produced and as the first of these is published shortly after the AGM it seemed a good idea to include a report of the AGM at that time. The formal Chairman's Report would continue to be given at the AGM as usual.

Peter Ford  
Secretary

## **Report of the Annual General Meeting held October 2005**

The AGM took place in Lecture Theatre A of the Civil Engineering building at the University of Leeds on Saturday, 29<sup>th</sup> October. Committee members present were Denis Weaire (chairman), Peter Ford (secretary/treasurer), Malcolm Cooper (Newsletter editor), Neil Brown, Christopher Green, Adrian Jackson, and Peter Rowlands; nine other members were also in attendance.

All the present members of the committee were re-elected. One additional member, Stuart Richardson a teacher from Sutton Coldfield, was also voted on to the committee.

Two important matters arose during the committee meeting. The first was the necessity to establish better links with the Education Group of the Institute of Physics. The second was closer interaction with the History group of the European Physical Society. It was agreed that these two matters should be vigorously pursued.

A lecture programme preceded the AGM. Dr John Lydon from the University of Leeds gave a brief introduction highlighting the important contributions made by the city both in science and technology, especially the beginnings of the industrial revolution.

Three lectures followed:

“Conical refraction – the radiant stranger” Professor Denis Weaire, Trinity College, Dublin.

“The scientific work of the Braggs”. Dr. Jeff Hughes, University of Manchester.

“The Braggs and Astbury - Leeds and the beginnings of Molecular Biology”. Professor Tony North, University of Leeds.

In addition, Dr. Peter Ford showed a short video (ten minutes) of W.H. Bragg lecturing at the Institution of Electrical Engineers around 1934.

Malcolm Cooper gave a brief address on the background to the special issue of the newsletter: 'Apologia pro Vita Mea' and 'Early Reminiscences of Barr and Stroud Rangefinders', originally due to Professor William Stroud. After the meeting copies of the booklet – which seems to have been well received - were distributed and it has subsequently been distributed to the members of the History of Physics Group.

Finally, it was tentatively agreed that the 2006 AGM should be held sometime in October in the city of Bath at the Bath Royal Literary and Scientific Institution.

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Query Corner

I hope the 'Special Issue' of the newsletter on the writings of Prof. William Stroud has provided some interesting and amusing reading. In the 'Apologia pro Vita Mea' Prof. Stroud refers (rather cryptically) to the 'Quaker method of subtraction' and which apparently was the method as taught by Prof. Silvanus P Thompson at University College, Bristol. Despite considerable efforts to throw some light on this 'method' - it still remains a mystery. So I appeal to any of our readers who may know something about this to please contact me and any answers or even just comments may be included in future issues.

Malcolm Cooper

Editor

A Welcome to Leeds

(and science-technology heritage trail of Leeds starting from the Civil Engineering Lecture Theatre)

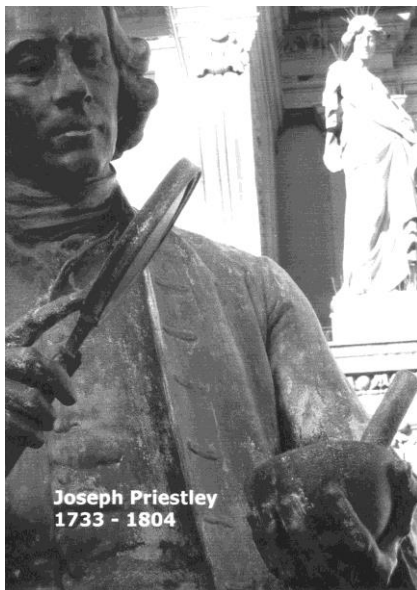
*Dr. John Lydon,
University of Leeds*

If you walk out of the front door of this building, turn left and walk for ten minutes along Woodhouse Lane and across the piece of parkland called Woodhouse Moor, you come to Hyde Park Corner. This is the site of the first telephone in Europe. A few yards further, and, on your right hand side, you will see Cumberland Road where the Braggs lived when they were doing their Nobel Prize-winning work immediately after the Great War. On the other side of the Road is the site of the old Wool Institute Research building, where Martin and Synge won their Nobel prize for the development of chromatography. Ten minutes more walking will take you to Headingley where William Astbury (pioneer of molecular biology) lived. - But more of him later from Prof. North.

If instead, you turn right outside this building, in a hundred yards you will come to the Chemistry Department, where, in the bad winter of 1947, Kathleen Lonsdale, taking advantage of the low temperatures, put an X-ray diffraction camera on the roof of the building and solved the crystal structure of ice and hexamethylbenzene, showing definitively that the aromatic ring *was* flat and the carbon-carbon bonds were all of the same length (a piece of physics that solved, with no room for argument, one of the central questions in organic chemistry). Beyond this building were the old physics and engineering departments of William Stroud and Archibald Barr, the Braggs and Edmund Stoner.

If you continue walking down the hill into town, you will find, in an alley opposite W.H. Smith's, a blue plaque marking the place where, in 1824, the Leeds bricklayer, Joseph Aspdin invented Portland cement. Less than a hundred yards away, in Commercial Street is the Leeds Library, the private subscription library started by

Joseph Priestley in 1780. A further hundred yards will take you past the site of the world's first traffic lights, to Mill Hill, the site of Priestley's church where he discovered nine gases, demonstrated the chemistry of photosynthesis, invented carbonated drinks and rewrote the book – literally and metaphorically, on electricity and magnetism.

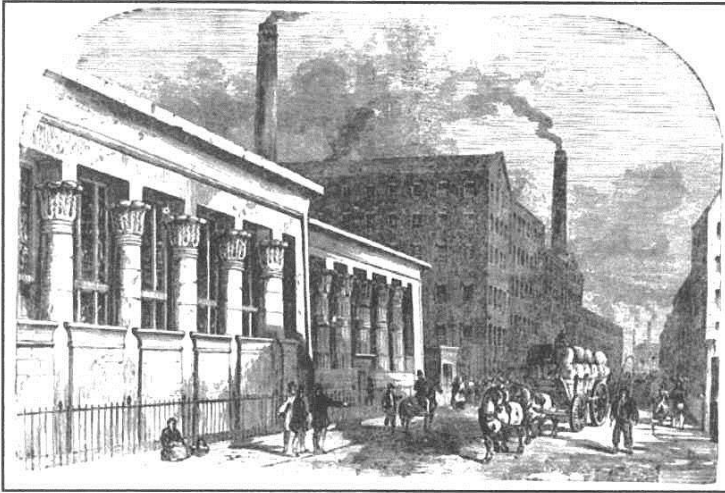


The statue of Joseph Priestley on the site of his old chapel, Mill Hill (City Square Leeds)

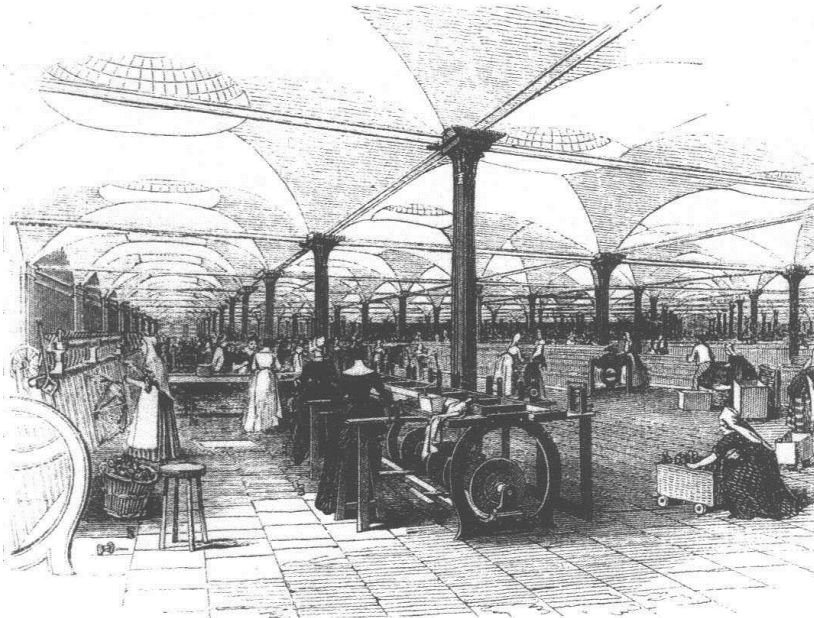
A fine statue in City Square depicts him frozen in the act of discovering oxygen, focussing sunlight onto mercury oxide (in a mortar, for some reason, with the pestle left in it).

If you are travelling back by train, from the elevated position of the western platforms you can see a pair of fine Italianate factory chimneys, dating from the beginning of the industrial revolution that brought in unequal measures prosperity, poverty and pollution to Leeds.

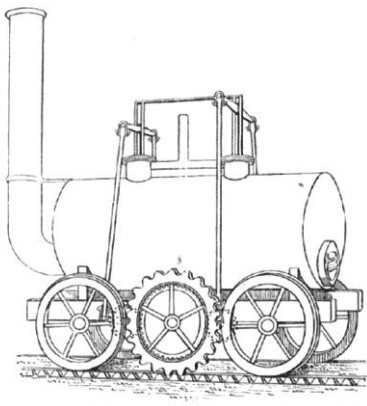
Behind them is the site of the Round Foundry where Matthew Murray built the finest steam engines of the day – and around that, the land which the malevolent James Watt bought up to stop him expanding his business – and the Tower which Watt built to spy on the activities of Murray's workforce. But even more remarkable, there is John Marshall's 1830 *Temple Mill*. The exterior in a strange Egyptian style modelled on a temple at Edfu on the upper Nile – but there is nothing classical about the interior. This was arguably the first modern factory in the world - all on one level under a single roof, gas lighting, and with the temperature and humidity control required for flax spinning.



Marshall's Temple Mill, Exterior and Interior



This square mile of land has as much right as anywhere on earth to be called the cradle of the industrial revolution.



The locomotive designed and built in 1812 by Matthew Murray at the Leeds Round Foundry for John Blenkinsop's Middleton Railway

It was here that the Kitsons built the railway locomotives for four continents and the steam farm engines that opened up the American Mid West to agriculture. By rights, this should be a World Heritage Site. If alternatively, you are travelling south by road you will notice that for the first half mile of it towards the M1, the M621 is a raised motorway. It carries you over the Middleton Railway – the oldest working railway in the world.

This is city with a deep history of science and technology,

Welcome to Leeds

Conical refraction: the radiant stranger

*Prof. J G Lunney, Prof. D Weaire
School of Physics, Trinity College Dublin*

The Irish poet Aubrey de Vere called conical refraction “the radiant stranger”, and it was apt enough. It was a totally unanticipated theoretical prediction by William Rowan Hamilton that met with immediate experimental confirmation – the very model of idealised modern science.

In conical refraction, a cone of rays is observed instead of the two rays in double refraction by a crystal.

By 1832 Fresnel’s wave theory of light had become one of the most worked-over topics in physics, yet an important detail had escaped attention in both theory and experiment. The latter is the more excusable lapse, because the experiment requires a suitable crystal of good quality– one that is *biaxial*. Moreover the effect is a small one in practice: the cones of refraction have angles of a few degrees at most and the two forms of the effect (internal, external) require a ray to be incident on the crystal in particular directions.

Inspired by the dramatic prediction, Humphrey Lloyd lost no time in verifying it. This excellent physicist is also remembered for other work in optics and in geomagnetism.

Many of Hamilton’s contemporaries must have felt disappointed that they had been less assiduous. A Trinity colleague, James MacCullagh, was distraught to the point of launching a pointless retrospective campaign for credit. That failure, and his general eclipse by Hamilton, may have contributed to the eventual suicide of MacCullagh in 1847. Fresnel did not live quite long enough to suffer any pangs of remorse at his oversight.

Whether the conical refraction story was a triumph for the wave theory of light (as distinct from those that are based on particles) was debatable, as Stokes insisted, but Hamilton's success certainly added momentum to its growing acceptance. The discovery was no paradigm shift, despite being totally unexpected. It was a confirmation of a growing orthodoxy.

For Hamilton it was a crowning achievement, a realisation of his precocious promise, and surely the motivation for the conferral of a knighthood by the Lord Lieutenant of Ireland at the BAAS meeting which followed in Dublin.

It has been said that Hamilton claimed that his theory was so secure that it had no need of experimental validation. If so, it must have been a rare jest from this serious man, for he did not regard the theory as a closed book. He did everything he could to encourage and assist Lloyd in his difficult task.

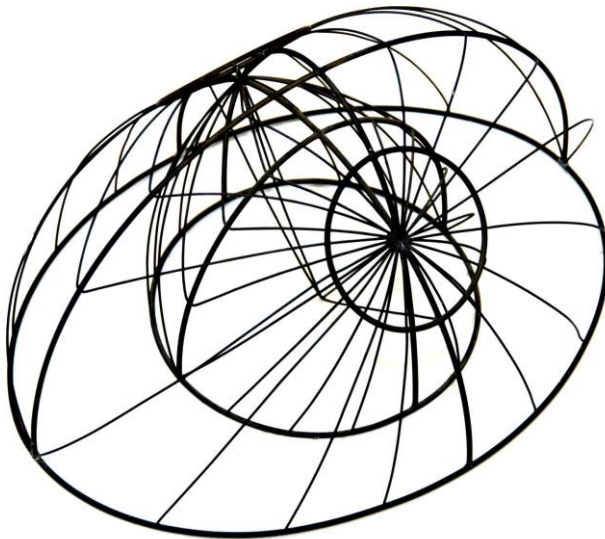
Isaac Todhunter did make the jocular remark that, having taught this subject all his life he did not want to have his ideas upset by a demonstration. Those ideas might well have been upset by some of what follows below.

James O'Hara, in his 1982 telling of the story, wrote that it was "it was little more than a curious optical phenomenon which had no conceivable application". After being highlighted in some of the optical textbooks of the 19th century, conical refraction had indeed been consigned to the lumber-room of miscellaneous minor curiosities. Preston's compendious work included it, but with no great drama. At about the same time Fletcher seems to have completely ignored it in his otherwise exhaustive treatment of double refraction, *The Optical Indicatrix and the Transmission of Light in Crystals* (1892).

But lately conical refraction has been taken out and dusted off. Like most antique curiosities in physics, it contains further layers of intriguing detail if closely examined. And in the age of lasers and optical communication the search is on for novel applications.

Theoretical obscurities

Whether pursued with algebra (as Hamilton did) or with geometry (as many physicists would prefer), an understanding of conical refraction requires an extensive background of optical theory. Its literature, old and new, is obscured by an extraordinary variety and ambiguity of basic nomenclature, both old and new, and not easily assimilated.



An elegant and rare wire model of the wave (or ray) surface of a biaxial crystal – possibly dating from the time of Humphrey Lloyd.*

A radial line drawn in most directions will encounter two parts of the wave surface, the inverse radii giving the velocities of two possible waves in that direction, having different polarisation.

*Readers who can comment on this, please do so - Editor

But two directions (together with their opposites) are very special: only a single velocity is found, because the inner and outer surface meet in a *cusp* consisting of two opposed cones. These special lines are called the *optic axes*, or *binormals* (or indeed several other names).

At first sight these binormals might seem *less* interesting than the general directions that yield two distinct wave velocities and hence are associated with double refraction, but Hamilton saw that even more exotic extraordinary refractive properties are associated with the binormals.

Conical refraction arises from the properties of these two kinds of special directions in the crystal.

The original experiment of Lloyd was that of external conical refraction, which produces a diverging hollow cone of light emerging from the crystal. He had no success until he obtained a particularly good crystal of aragonite from a commercial supplier. With this he demonstrated external conical refraction, measuring a cone angle of about 3 degrees, as predicted.

His experimental arrangements may today be simplified, if a crystal is cut so that its faces are normal to either one of the special directions. And lasers provide convenient bright beams, making demonstrations possible even on a large scale.

Lloyd was a thorough experimentalist, a fitting counterpart to Hamilton, the systematic theorist. Not content with seeing the phenomenon as predicted, he examined the polarisation of the emergent light, and was surprised to find that “every ray of the cone was polarised in a different plane”.

The finer details

As early as 1839, the bright ring exhibited by internal conical refraction was resolved by the experiments of Poggendorf into two concentric rings. (Everything seems to come in twos in this subject.) The same is true of the external case. With modern equipment additional, fainter rings are discernible, and Lloyd's simple manifestation of the effect becomes a complex pattern and a fresh challenge to theory.

The extra structure appears because the light beams that are used are of finite extent, rather than those idealised rays, mere lines, upon which the elementary theory is based.

A singular case

Often in constructing (or deconstructing) the history of science, its manner of progress is falsified for the sake of clarity. The electron was not discovered by JJ Thomson on a certain day in Cambridge, but we tell it so. The case of conical refraction is an exception for which the revelatory process is unambiguous, and priority is sharply defined - in spite of the anguished protestations of MacCullagh. It is a tale of two virtuous and dedicated scientists who richly deserved the accolades that they received; a tale worth recounting for generations to come. The emergence of the radiant stranger can still startle, entertain and educate us.

A full version of this article is to be submitted to Europhysics News. See also David Wilkins' article 'William Rowan Hamilton: mathematical genius' in the August 2005 issue of Physics World.

The Braggs and Astbury: Leeds and the beginning of Molecular Biology

*Anthony North, Astbury Professor of Biophysics (Emeritus)
Astbury Centre for Structural Molecular Biology,
The University of Leeds*

William Henry Bragg was born in Wigton, Cumbria in 1862 and graduated in Mathematics from Cambridge in 1885. He came 3rd in the final examinations (a position known as 3rd Wrangler). In his final year he had done some work in the Physics department and become known to J J Thomson (later a Nobel Laureate for his discovery of the electron); shortly after graduating he was encouraged by Thomson to apply for the position of Professor of Mathematics & Physics at the University of Adelaide. He was duly appointed to the post and set sail for Australia - the lengthy sea voyage gave him the opportunity to read up some more physics!

W H Bragg in Adelaide

On his appointment in 1886, he found that, with just one assistant, he was entirely responsible for all the mathematics and physics teaching in the University, adding up to 18 hours per week plus 6 hours evening FE classes. In order for his students to do practical work, he apprenticed himself to a firm of instrument makers to make apparatus for his classes - and his interest in instrumentation was to prove important in later years.



But it was not all hard work - he was an excellent tennis player and joined in the social life of Adelaide. He met Charles Todd, who held the posts of South Australian Government Astronomer, Postmaster-General and Superintendent of Telegraphs. Todd had been responsible for constructing the telegraph line from Adelaide to Darwin and had named the staging post 'Alice Springs' after his wife. WHB got to know Todd's family and in 1889 he married Gwendoline Todd, with whom he had 3 children, William Lawrence, Robert and Gwendolen.

Initially, he had little opportunity for research, (and, indeed, said in later years that it had never occurred to him to do any) but he was very interested in the developing ideas about electromagnetism, wireless and, particularly, radioactivity; and he constructed apparatus for demonstrating these phenomena to his students.

It was not until 1903 that WHB carried out his first serious independent research; he acquired some radium and carried out experiments on radioactivity, alpha & beta particles and gamma rays.



X-ray of Bragg's hand

Röntgen had discovered X-rays in 1895, but their nature was the subject of controversy. WHB took X-ray pictures of his own hand and of his son's elbow, hurt in a cycling accident. At this time, there was controversy about the nature of X-rays – were they particles or waves? WHB became a proponent of the idea that X-rays were

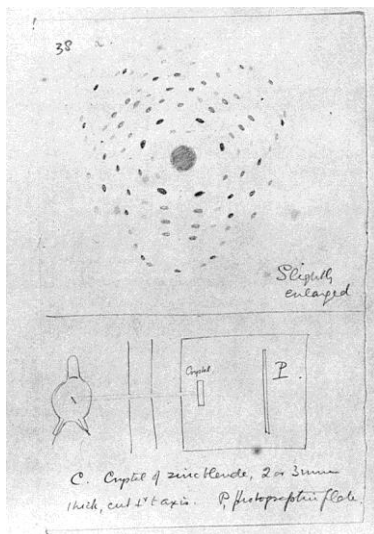
particles and he had detailed correspondence with Rutherford and others. He became known internationally and was elected FRS in 1907. He had, however, become concerned that Adelaide was remote from world-leading laboratories and considered a move;

the possibility of succeeding Rutherford at McGill University in Canada was frustrated by a serious fire there, but in 1908, he was invited to the Cavendish Chair of Physics in Leeds succeeding Professor William Stroud.

W H Bragg in Leeds

WHB and his wife were initially unhappy in Leeds; the city was dirty with poor housing and his research seemed to have stagnated. He continued to be engaged in a controversy with Barkla as to whether X-rays were waves or corpuscles. (In retrospect, Bragg had been studying high-energy rays and Barkla softer, low-energy rays, so they had been observing different properties.)

However, all was to change in 1912, when von Laue, Friedrich & Knipping shone X-rays on to crystals and obtained a pattern of spots on photographic film. But, were the spots on the film due to corpuscles passing through channels between the atoms in the crystal or to waves diffracted by the atoms?



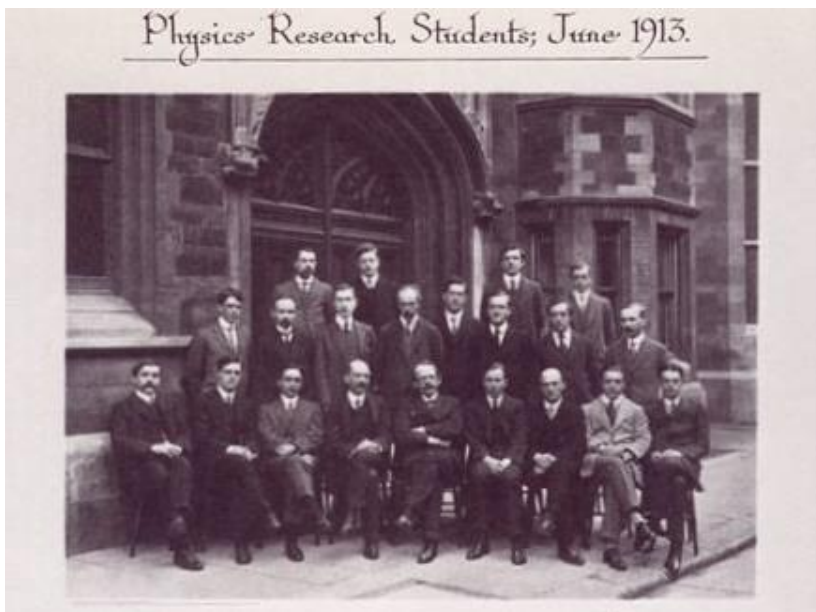
WHB wrote to Arthur Schuster enclosing this diagram.

“I enclose a drawing of the curious x-ray effect obtained by Dr Laue in Munich. It is claimed, I understand, that it is a diffraction effect due to the regular arrangement of the molecules in space”

Cambridge

WHB's elder son (WLB) had studied in his father's department in Adelaide, but he had moved to England with the family in 1909 and, in 1912, he graduated in physics in Cambridge.

The Cavendish Laboratory, Cambridge, 1913



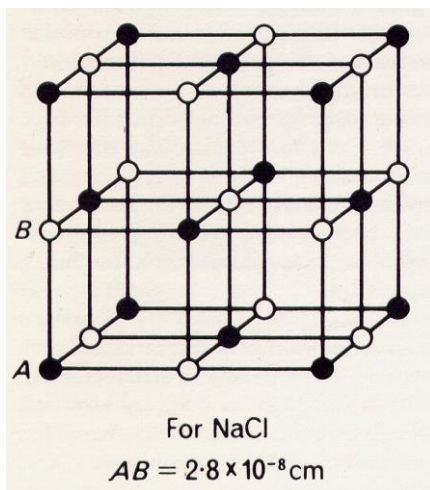
WD Rudge RW James WA Jenkins JK Robertson
 WL Bragg VJ Pavlov S Kalandiyk FW Aston HA McTaggart H Smith F Kerschbaum AN Shaw
 RD Kleeman AL Hughes R Whiddington CTR Wilson JJ Thomson F Horton RT Beatty AE Oxley G Stead

R Whiddington became Professor of Physics in Leeds, RW James became a leading crystallographer in South Africa, and apart from WL Bragg were three other Nobel Prize winners: FW Aston became known for his work on isotopes and received the Nobel Prize for Chemistry in 1922, JJ Thomson received the Nobel Prize for the discovery of the electron, CTR Wilson received the 1927 Nobel Prize in Physics for his invention of the cloud chamber.

While in Cambridge, WLB was of course intrigued by the results of Laue, Friedrich and Knipping, for which they had produced a complicated explanation and, in late 1912, he had his ‘brain wave’: the pattern of spots in the X-ray pattern from a crystal could be explained by ‘reflection’ of waves from crystal planes, analogous to light rays from a mirror.

He published his idea in a paper entitled “The diffraction of short electromagnetic waves by a crystal” in *Proceedings of the Cambridge Philosophical Society* in late 1912. The title was carefully chosen – he did not want directly to contradict his father’s view that X-rays were actually particles. The facilities for doing experiments with X-rays in Cambridge were rather poor, whereas WHB had constructed an X-ray spectrometer in Leeds, which gave much more reliable measurements than the Cambridge cameras and films. During the vacations, WLB worked in his father’s labs and during 1912-13, the 2 men worked together, observing X-rays reflected from cleaved mica and then deriving the arrangement of atoms in simple inorganic crystals, including NaCl and KCl.

An aside - Sodium Chloride



For a long time, chemists refused to accept the fact that NaCl contains no NaCl molecules, the crystals containing just an alternating array of Na^+ and Cl^- ions. WLB used to recall chemists trying to persuade him that the Na^+ and Cl^- ions were not exactly equidistant from each other, but that they might be arranged in pairs just a little closer to each other!

Even as late as 1927, Professor H E Armstrong wrote in a letter to Nature:

“Professor W L Bragg asserts that in Sodium Chloride there appear to be no molecules represented by NaCl. The equality in number of sodium and chlorine atoms is arrived at by a chess-board pattern of these atoms; it is a result of geometry and not a pairing-off of the atoms.

“This statement is more than ‘repugnant to common sense’. It is absurd to the nth degree, not chemical cricket. Chemistry is neither chess nor geometry, whatever X-ray physics might be. Such unjustified aspersion of the molecular character of our most necessary condiment must not be allowed any longer to pass unchallenged. It were time that chemists took charge of chemistry once more and protected neophytes against the worship of false gods; at least taught them to ask for something more than chess-board evidence.”

1914 and onwards:

UCL, Manchester and the Royal Institution

During the first world war, WHB became much involved with scientific advice to the government and decided to move from Leeds to University College, London, to be nearer the centre of national activity. WLB was on active service in France developing acoustic range-finding methods for directing gunfire and was invested with the Military Cross. Sadly, his younger brother Robert was killed in action.

In 1915, WHB and WLB were awarded the Nobel Prize. This is still the only example of the joint award of a Nobel prize to father and son and WLB remains the youngest recipient of a Nobel prize at the age of 25.

After the war, WHB and WLB continued their X-ray diffraction studies, but agreed to work on different aspects.

After a few months back in Cambridge, in 1919 WLB succeeded Ernest Rutherford in the Langworthy Chair of Physics in Manchester, and for many years he concentrated mainly on metals and minerals, especially the silicates, and on the development of diffraction methods.

Meanwhile, WHB had built up a research team at University College London, working largely on organic substances. While there, he wrote: *“My son and I have been comparing notes and we find that we can only get a few hours each week for research”* - an experience shared by most present-day academics!

In 1923, WHB succeeded Sir James Dewar as Resident Professor and Director of the Davy-Faraday Laboratory at the Royal Institution, where he would be free from routine teaching. He took with him members of his UCL team, including William Astbury and Kathleen Yardley (later Lonsdale). Other research workers at the R.I. included J M Robertson (for many years a leading chemical crystallographer in Glasgow), E G Cox (later Professor of Structural Chemistry in Leeds and subsequently Director of the Agricultural Research Council) and J D Bernal, who became an important innovator of studies of biological structures in Cambridge and London.

At the R.I., WHB re-established the series of lectures to lay audiences that had been started by Davy and Faraday and he asked Astbury to take an X-ray diffraction picture of a human hair for a lecture on “the imperfect crystallisation of common things”. Astbury had been doing good crystallographic work, notably preparing with Kathleen Yardley the first edition of what was to become the crystallographers’ ‘bible’, the International Tables of crystal symmetry relationships. Taking the fibre diagram of hair stimulated Astbury’s interest in the structures of natural polymers.

The Vice-Chancellor of the University of Leeds, James Baillie, had decided in 1928 that the Department of Textile Industries needed to be enlivened by the appointment of a Lecturer in Textile Physics and WHB was among the people consulted about the appointment; he wrote to Professor Aldred Barker:

"I have a man here who might possibly make you the research scientist you want – W T Astbury. He is a really brilliant man, has done some first class work which is quoted everywhere He has considerable mathematical ability and a very good knowledge of physics and chemistry He is very energetic and persevering, has imagination, and, in fact, he has the research spirit. Although not trained in the workshop he is sufficiently skilful with his hands. He is a most loyal colleague to me and I do not want to lose him at all but it is good for these people to make a move from time to time. He can lecture, though I do not call him a very good lecturer, he can write a great deal better than he can speak."

Despite the latter reservation, Astbury was appointed to Leeds as Lecturer in 1928, where he was to spend the rest of his life, becoming Professor of Biomolecular Structure in 1945.

Astbury in Leeds

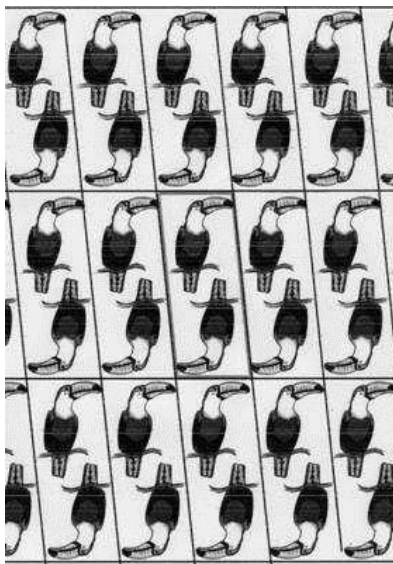


In those days, all textiles were made from naturally-occurring fibres such as wool, silk and hair. Astbury set out to show that these were more than the “biochemically lifeless and uninteresting material” they were often claimed to be.

The Nature of Fibrous Materials

Normal crystals are made up from a regular pattern of 'unit cells', each of an identical shape and content, which fill space in 3 dimensions. Each unit cell contains one or more molecules, packed together in a symmetrical way. In this example, each cell contains two 'molecules'.

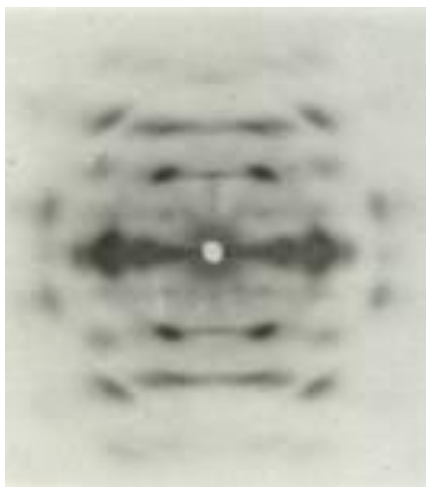
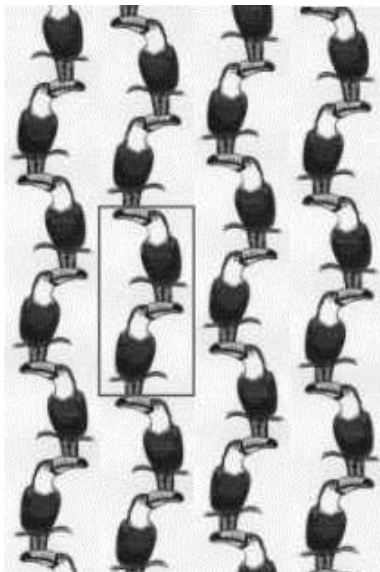
We can only show one layer of 'molecules' in this picture – the complete crystal would be formed by stacking layers one above the other.



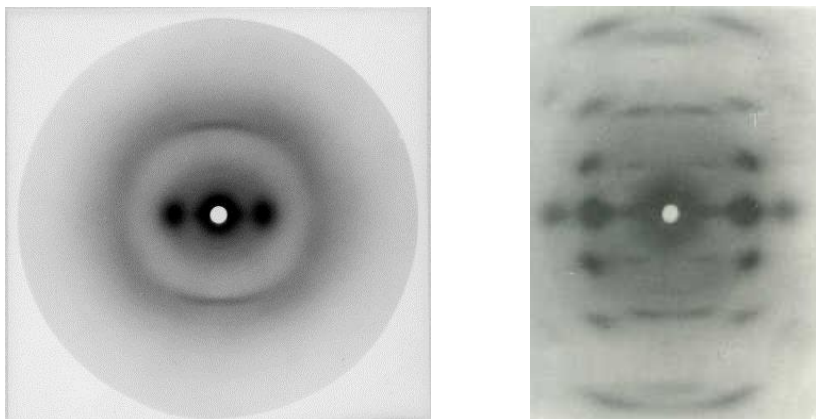
Fibrous molecules such as the biological macromolecules cellulose, wool, silk and DNA too are very long and, in the fibre, are parallel to each other, but they are not always lined up longitudinally with their neighbours on either side – see below. We can, however, still have 'unit cells', with the molecules passing through from one cell to the next along the chain, each unit cell containing a number of the monomer units from which the chain is composed. As with normal crystals, we still have regular lateral spacings between unit cells and regular spacings along the chain, but we have lost some of the regularity of a normal crystal when the chains are not in register sideways.

Consequently, when an X-ray beam is shone at right angles to a fibre, the 'fibre diagram' obtained tends to show not the regular array of well-defined spots as from a crystal, but a pattern of more diffuse spots and arcs.

Cellulose, the major structural polymer of plants, is a very simple unbranched polymer of identical glucose units and the X-ray pattern from cellulose – below – is therefore quite sharp.



Successive glucose units, each 5.15 \AA long, face in alternate directions, like the toucans above, giving an exact repeat of 10.3 \AA along the fibre axis.



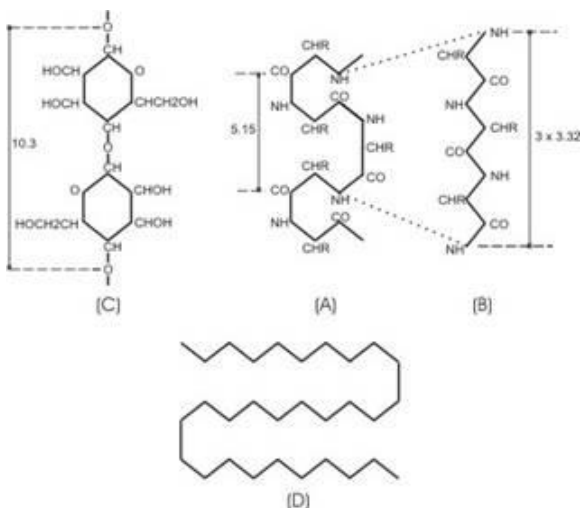
In contrast, the X-ray pattern from hair and wool, the ‘alpha’ pattern (above left) is very diffuse, as they are proteins made up from a rather irregular sequence of the 20 different types of amino acid. Nevertheless, the positions of the spots and arcs give information about the geometry of the chains and their spatial arrangement.

The pattern from silk, the ‘beta’ pattern (above right), is intermediate in form because, although it too is a protein, there is greater regularity in its amino-acid sequence.

Astbury found that, while wool and hair (both forms of the protein keratin) normally gave the alpha type of pattern, they could be stretched in suitable solvents to give a beta type pattern like that from silk. He made the extremely important deduction that, in the alpha state, the molecules were highly folded, but in the beta state they were stretched out.

Measurements of the alpha pattern gave a longitudinal periodicity of 5.15\AA – remarkably similar to half the periodicity (10.3\AA) of a cellulose fibre. He found a periodicity of 9.96\AA for the beta state. Intrigued by the relationship of the alpha spacing to that of cellulose, he proposed a model (A, below) for unstretched wool in which the protein chain was bent back on itself in a shape rather like the glucose rings of cellulose (C).

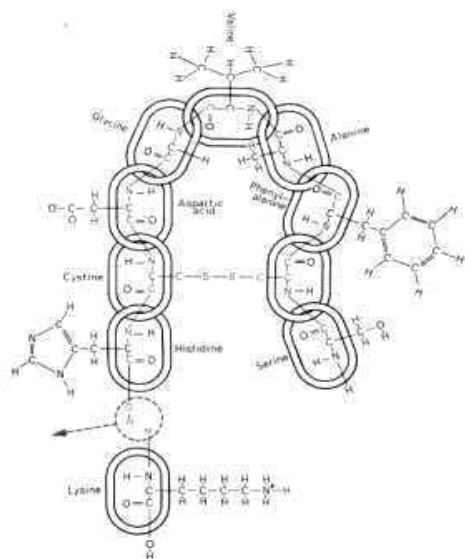
For the beta form, he put forward a model for the stretched-out protein chain.



D represents the 'cross-beta' form of protein chains, described later.

The Structure of Protein Chains

Protein molecules are polymers of 20 different kinds of monomer - the amino acids. As the chain is synthesised on the ribosome, each additional amino acid is added to the carboxyl end of the growing chain with the elimination of a water molecule (bottom right).



The amino-acid side chains have widely differing sizes and properties:

- positively charged, e.g. lysine
- negatively-charged, e.g. aspartic acid
- neutral polar, e.g. serine
- non-polar aliphatic, e.g. alanine, valine
- non-polar aromatic, e.g. phenylalanine
- cystine, which cross-links two different parts of the chain, stabilises (but complicates) the overall chain fold.

Astbury's classification of fibrous proteins

Probably his major contribution to the field was Astbury's wide studies of the mechanical properties, physical properties (such as density) and X-ray diagrams of as many naturally occurring fibrous polymers as he could find, which led to the following generally accepted classification:

collagen (the material of tendons, and supporting matrix of bone and skin)

the k-m-e-f group:

keratin (wool, hair and silk)

myosin (one of the major muscle components)

epidermin (a skin component)

fibrinogen (a blood clotting agent)

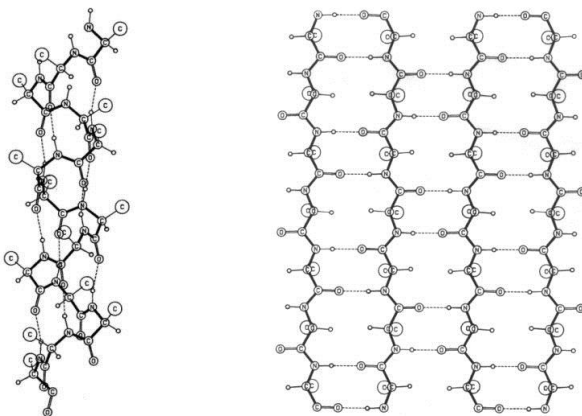
As shown by their X-ray pictures, members of the k-m-e-f group can exist in 2 forms, alpha and beta, the alpha form being convertible to beta by stretching; Astbury speculated that this could be the mechanism for muscle contraction, but we now know that this is not so – muscles contract by the myosin filaments sliding past filaments of actin, a very different kind of polymer.

It was found that some k-m-e-f members could exist in a 3rd structural form, known as ‘cross-beta’, in which the molecules ran at right angles to the overall direction of the fibre; these included a component of bacterial flagella and the egg-stalk of the lacewing fly, which lays its eggs on a little pillar on top of a leaf. Some globular proteins, when denatured, also adopt the ‘cross-beta’ form.

The alpha – beta transition can explain the process of forming ‘permanent waves’ by chemical treatments that cause fibres on opposite sides of a hair to be stretched differentially and it also explains the shrinking of wool. The distinguished crystallographer A L Patterson wrote:

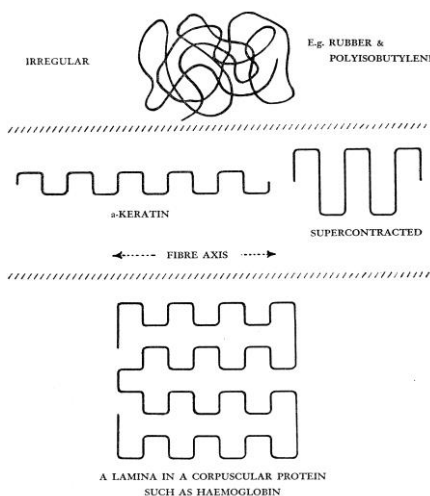
*Amino acids in chains
Are the cause, so the X-ray explains,
Of the stretching of wool
And its strength when you pull,
And show why it shrinks when it rains.*

While Astbury’s deduction that stretching fibres involved a change in molecular conformation that resulted in the change of physical length was undoubtedly correct, the actual molecular geometries that he proposed, especially for the shorter form, were not. The correct geometries were discovered by the Americans Linus Pauling and Robert Corey, who deduced that the alpha form was a helical shape (with 3.6 amino-acid units per turn) rather than the flat ribbon proposed by Astbury; in the beta form, the chains were nearly fully-extended, as Astbury had suggested, but with a slight ‘crimping’. Where had Astbury gone wrong? As a crystallographer, Astbury had concentrated on the molecular geometry and expected it to be regular; Pauling was essentially a chemist and based his structures on the realisation that, first, the atoms in the peptide group (the link between consecutive amino acids in the chain) should be coplanar, and, second, that the structures should be stabilised by linear hydrogen bonds between NH and CO groups. Satisfying these constraints was more important than maintaining crystallographic symmetry.



Pauling and Corey's alpha and beta models

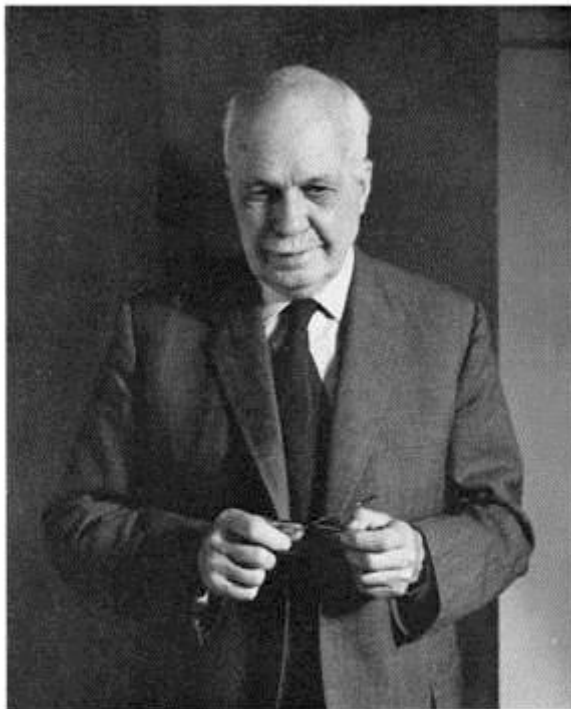
Astbury was of course interested in the globular proteins that are responsible for the body's various metabolic functions and he envisaged that the protein chains in them would be folded back and forth in a regular fashion, for example in the form of uniform stacks of sheets or ribbons.



Here again, while the essence was right, the detail was not.

W L Bragg in Cambridge and London

In 1937, WLB moved from Manchester to be Director of the National Physical Laboratory, but his stay there was short-lived, because Sir Ernest Rutherford died unexpectedly and WLB was invited to succeed him in 1938 as Cavendish Professor in Cambridge.



W L Bragg

Hardly had he arrived when war delayed his full-time attention to his department, but he had already been excited by the discovery by J D Bernal and Dorothy Crowfoot (later Hodgkin) that globular proteins could be crystallised provided they were prevented from drying out. Another arrival in Cambridge had been Max Perutz, enthusiastic to find the 3-dimensional structure of haemoglobin. WLB managed to

obtain funding from the Medical Research Council to support work on globular proteins, eventually giving rise to the MRC Laboratory of Molecular Biology, probably the most successful laboratory in the world, certainly as measured by Nobel Prizes won by its members. Perutz was joined by John Kendrew, and together they were responsible for the 3-dimensional structures of the first two globular proteins, haemoglobin (the oxygen-carrier) which has 4 similar chains and myoglobin (the oxygen-storage protein in muscle), a simpler molecule with just one chain, like those in haemoglobin.

In each of the myoglobin and haemoglobin chains, an oxygen molecule is carried by the iron atom at the centre of the flat haem group, which is enfolded by the protein chain (right).

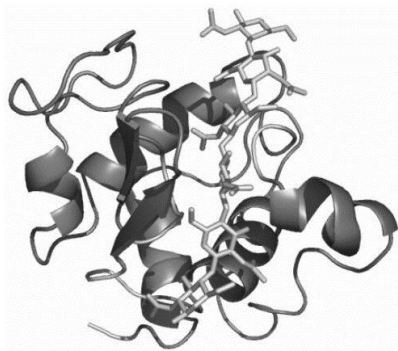


The myoglobin chain and each of the two different types of haemoglobin chains are composed of about 8 segments, each in the form of alpha helices. As Astbury had suggested, this globular protein consists of one of the typical fibrous protein conformations folded into a compact near-spherical shape – but the overall fold was nothing like as regular as he had envisaged.

As the work on haemoglobin and myoglobin was progressing, WLB made the final move of his career. Just as it had done before his father had moved there, the Royal Institution was again in need of a firm directing hand, and WLB was persuaded to take over there in 1955. (WHB had died over 10 years previously.) However, WLB did not sever his links with Cambridge and he obtained support from the Medical Research Council to appoint new research staff at the R.I. who initially worked closely with Perutz and Kendrew on determining the haemoglobin and myoglobin structures.

With those projects having reached fruition, the R.I. team went on to obtain the structure of the third globular protein, lysozyme, an anti-bacterial enzyme whose function is to break down bacterial cell walls

by cutting a polysaccharide component of the bacterial cell wall; the enzyme can bind 6 rings of the polysaccharide and cuts the chain between the 4th and 5th ring from the top..



This was the first enzyme of known 3-dimensional structure, which permitted the catalytic mechanism to be deduced. Its structural interest, however, is that the lysozyme molecule is again an irregular shape, but,

while some parts of the chain have a helical fold, others are in the form of elongated beta-type strands.

The occurrence of alpha and beta folds in different proportions in globular proteins is a general property; in some cases the beta conformation predominates, as in the mouse major urinary protein, (below right) a component of the urine of male mice, which carries a pheromone molecule that acts on female mice. It is a member of the lipocalin family, several of which structures have been determined in Leeds in recent years.

These two structural motifs are to be found in the very large protein molecules and in macromolecular complexes such as viruses – work on a number of such systems is in progress in Leeds, led nowadays by Simon Phillips and colleagues in the Astbury Centre.



Astbury on protein denaturation

Globular proteins can quite easily be ‘denaturated’ by heat or chemical attack into a random, unfolded form. Astbury was fascinated by the fact that fibres could be formed from denatured globular proteins, and on wearing a pullover made of a yarn spun from a globular protein, he wrote (in 1936):

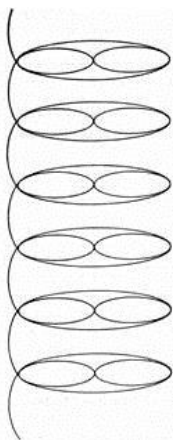
“Only the other evening, I was watching my daughter knitting yarn spun from monkey-nut protein – a protein, I repeat, with round molecules that once seemed to bear no relation whatsoever with fibres – and as I touched the knitting, again the wonder of it all flooded over me”.

This sort of phenomenon has recently taken on great medical importance as it has now become apparent that a number of diseases such as Alzheimer’s, Creutzfeld-Jacob’s disease and Type II diabetes are associated with the misfolding of protein chains – most remarkably into the ‘cross-beta’ type of fold that Astbury’s group had first observed. Work on protein folding and misfolding is now being pursued in Leeds by Sheena Radford and her group.

Astbury’s ideas on nucleic acids

DNA can be extracted from cells into a gel form, from which it is possible to draw out fibres in which the molecules are aligned. Members of Astbury’s group took X-ray pictures of such fibres which showed a regular axial repeat of 3.34\AA . Astbury recognised this spacing as being similar to the thickness of flat molecules such as graphite and benzene, and he knew that the 4 types of DNA ‘base’ (A,T,G and C) are just such flat molecules; he therefore deduced that DNA bases are stacked on top of each other “like a pile of pennies”.

He also thought that the similarity to the periodicities in fibrous protein structures was significant, but in this respect he was wrong.



Astbury's 'pile of pennies' model



Crick & Watson's model

Unfortunately for Astbury, for a variety of reasons, he did not take his DNA work any further and it was in WLB's lab. in Cambridge where the essential aspects of DNA structure were discovered by Francis Crick (who was supposed to be working on haemoglobin) and James Watson (a young American visitor). They deduced from the X-ray data that DNA molecules comprised two anti-parallel chains, like the stiles of a ladder, linked together by pairs of bases, A with T and G with C, which formed the rungs. Their double-helical model showed directly how this complementary base-pairing provided the basis of replication. The molecules can be copied exactly- if the 2 strands are pulled apart; new strands can only be assembled if the bases on each new "daughter" strand are again complementary to those of each "parent".

Crick and Watson's model depended entirely on X-ray data obtained by Maurice Wilkins and his colleagues (including Rosalind Franklin) in J T Randall's department at King's College, London, and the systematic 'refinement' of the model by Wilkins's group proved the correctness of the model. A further interesting connection is that Randall had been a student of WLB in Manchester.

Origins of the term ‘Molecular Biology’

It seems that the first published use of the term ‘Molecular Biology’ was by Warren Weaver, director of the Rockefeller Foundation’s natural sciences programme, in 1938: “Among the studies to which the [Rockefeller] Foundation is giving support is a series in a relatively new field, which may be called molecular biology, in which delicate modern techniques are being used to investigate ever more minute details of certain life processes.”

Astbury gave his own definition in 1961: “Molecular biology implies not so much a technique as an approach, an approach from the viewpoint of the so-called basic sciences with the leading idea of searching below the large-scale manifestations of classical biology for the corresponding molecular plan. It is concerned particularly with the *forms* of biological molecules and is predominantly three-dimensional and structural – which does not mean, however, that it is *merely* a refinement of morphology – it must at the same time enquire into genesis and function.”

Nowadays, the term has a rather wider connotation in that much molecular biology no longer has an explicit 3-dimensional structural quality, although a 3-dimensional structural under-pinning is implicit.

Astbury himself, when a chair was conferred on him, would have liked the title ‘Professor of Molecular Biology’; unfortunately a senior Leeds biologist expressed the view that, while Astbury knew a lot about molecules, he did not know any biology, so Astbury was given the title ‘Professor of Biomolecular Structure’. I think that the criticism was unfair as, while without a training in biology, Astbury was always aware of the biological implications of his work.

Astbury's conception of his role in science

In the opinion of his biographer, J D Bernal, Astbury was responsible for Leeds becoming the major centre of fibre research worldwide for more than 15 years following his appointment. He established the relationships between the gross (anatomical) structure of natural materials, their physical properties and their underlying molecular structures.

Astbury himself must have realised that, although he had laid the foundations in his derivation of relationships between structure at the molecular level and physical properties at the anatomical level, he had not succeeded in deriving the structural details of the major classes of biological macromolecules; he used the following quotation to illustrate what he thought his role had been:

“The which observ’d, a man may prophesy,
With a near aim, of the main chance of things
As yet not come to life, which in their seeds
And weak beginnings lie intreasured.”

(Shakespeare, King Henry IV, part 2)

Summary

I should like to end with a further quotation:

“Did we know the mechanical affections of the particles of rhubarb, hemlock, opium and a man, as a watchmaker does those of a watch.....we should be able to tell beforehand that rhubarb will purge, hemlock kill and opium make a man sleep.....”

*(John Locke in his Essay Concerning
Human Understanding (1620))*

I would claim that the work of the Braggs in 1912-1913 laid the foundations of X-ray crystallography as a method for the determination of the structures of materials and especially of those of biological origin. Astbury's work, from his arrival in Leeds in 1928 and using X-ray methods, was seminal in developing our understanding that the properties of living organisms could be understood from a knowledge of the structures and properties of their constituent molecules.

Through the work of these men and those who have followed them, we have progressed a long way to achieving Locke's aspiration.

Sources of material

Biographical Memoirs of Fellows of the Royal Society:

J D Bernal: William Thomas Astbury

Sir David Phillips: William Lawrence Bragg

G M Caroe: William Henry Bragg

John Jenkin: The Bragg Family in Adelaide

Robert Olby: The Path to the Double Helix

Graeme Hunter: Light is a Messenger (The life and science of William Lawrence Bragg)

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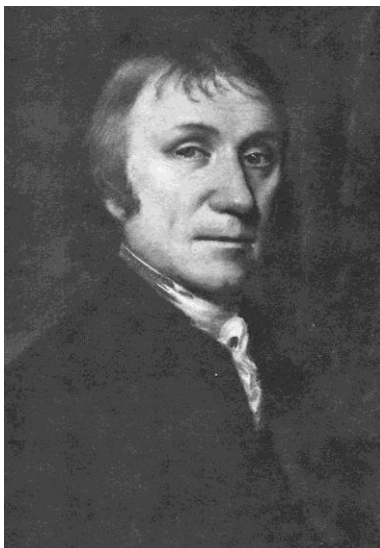
### **Disclaimer**

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## Joseph Priestley

*Dr. Peter Ford*  
*University of Bath*

This article was written in 2004 for the web site ([www.brlsi.org](http://www.brlsi.org)) of the Bath Royal Literary and Scientific Institution (BRLSI)\*



Joseph Priestley, National Portrait Gallery

This year marks the two hundredth anniversary of the death of Joseph Priestley one of the most influential and colourful scientists of the eighteenth century. He had a Bath connection since he was a member of the Bath Philosophical Society, a forerunner of the BRLSI, when he lived and worked at Bowood House in Calne, Wiltshire. There he was the librarian and scientific guru for Lord Shelburne, the Marquis of Lansdowne and it was here that he first identified oxygen. It is for this discovery that he is best remembered today.



Priestley was born in Birstal Fieldhead near Leeds in 13<sup>th</sup> March 1733, the eldest son of a cloth-dresser. His mother died when he was seven years old and his aunt mainly brought him up. He was educated for the dissenting ministry and spent much of his life both as a teacher and a preacher. Priestley was a true polymath writing books and articles on theology, history, education, aesthetics and politics as well as science. During his lifetime he was as well known for his views on theology and politics as for his work in science.

Priestley married Mary Wilkinson in 1762. She was the daughter of Isaac and sister to John and William Wilkinson. All three men were prominent iron masters in the eighteenth century.

His scientific interests began around the middle of the 1760s. It was during this time that he began to write his *History and Present State of Electricity*. For this work he received the help from several people. These included Benjamin Franklin (The American academic, politician and scientist who was present at the signing of the American Declaration of Independence), William Watson (An apothecary who lived in Bath and was also a member of the Bath Philosophical Society; he was also a friend of William Herschel) and John Canton (Another scientist born in the West country at Stroud in Gloucester in whose honour the Institute of Physics recently erected a blue plaque on his schoolhouse in Stroud). While writing the book he carried out several experiments. Among them was an ingenious demonstration of the inverse square law of electrostatics. This is generally known as Coulomb's law but the work of Priestley in fact predates that of Coulomb by nearly twenty years. Mainly as a result of his work on electricity, he was elected to Fellowship of the Royal Society in 1766.

In part as a result of financial problems stemming from his increasing family responsibilities, Priestley resigned a teaching position that he had to become the minister of Mill-Hill Chapel, which was a major Presbyterian congregation in Leeds. It was here that he completed his book, *History and Present State of Electricity* (1767) and also wrote the *History of Optics* (1772). While living and working in Leeds he became a founder member of the Leeds Library

becoming both its Secretary and later President. In 1989 the Leeds Library was prominent in setting up the Association of Independent Libraries to which the BRLSI also belongs. The Leeds Library holds important archival material on Priestley's time there. It was while he was in Leeds that he began his most important scientific researches namely those connected with the nature and properties of gases. A bizarre consequence of this is that Priestley can claim to be the father of the soft drinks industry. He found a technique for dissolving carbon dioxide in water to produce a pleasant "fizzy" taste. Over a hundred years later Mr Bowler of Bath benefited from this when he formed his soft drinks industry.

Priestley entered the service of the Earl of Shelburne in 1773 and it was while he was in this service that he discovered oxygen. In a classic series of experiments he used his 12inch "burning lens" to heat up mercuric oxide and observed that a most remarkable gas was emitted. In his paper published in the Philosophical Transactions of the Royal Society in 1775 he refers to the gas as follows: *"this air is of exalted nature...A candle burned in this air with an amazing strength of flame; and a bit of red hot wood crackled and burned with a prodigious rapidity, exhibiting an appearance something like that of iron glowing with a white heat, and throwing sparks in all directions. But to complete the proof of the superior quality of this air, I introduced a mouse into it; and in a quantity in which, had it been common air, it would have died in about a quarter of an hour; it lived at two different times, a whole hour, and was taken out quite vigorous."* Although oxygen was his most important discovery, Priestley also described the isolation and identification of other gases such as ammonia, sulphur dioxide, nitrous oxide and nitrogen dioxide.

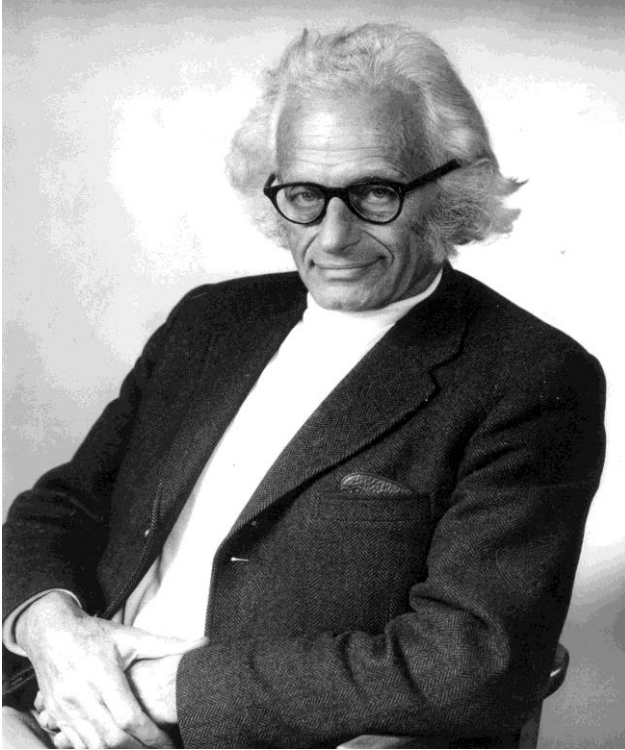
By 1780 the working relationship between Priestley and the Earl of Sherburne had cooled somewhat and he decided to move with his family to Birmingham and Priestley became preacher at the New Meeting House. This was one of the most liberal congregations in England. For Priestley his time at Birmingham was among the happiest in his life. He soon became involved with the Lunar Society – a small group of academics, scientists and industrialists

with wide ranging interests who were prominent in spearheading the Industrial Revolution in England. The Lunar Society was so named because its members met at full moon thereby facilitating travelling home in the dark after the meetings. Fellow members of the Lunar Society included Matthew Boulton, Erasmus Darwin (grandfather of Charles and also a pioneer in the theory of evolution), James Watt and Josiah Wedgwood. Although Priestley played an active role in the Lunar Society his interests turned more and more towards theology. He became an active dissenter with outspoken criticism of the established church. These were dangerous times to be alive with the French Revolution (1789-91), which Priestley supported, sending shock waves around Europe. In 1791 on the second anniversary of the storming of the Bastille a "Church and King" mob in Birmingham destroyed the New Meeting House as well as Priestley's house and laboratory. He barely escaped with his life and most of his equipment and records were lost. Priestley briefly joined a dissenting group in London at Hackney but after renewed vitriol against him and his family he emigrated to the United States of America in 1794.

He was warmly welcomed in America and offered the chair of chemistry at the University of Pennsylvania, which had been founded by Benjamin Franklin. Priestley declined and settled in Northumberland, Pennsylvania in an area intended for British émigrés fleeing political persecution. He was befriended by Thomas Jefferson, who became President of the United States in 1800. However, Priestley's final years were sad and lonely; his favourite son died in 1795 and his wife a year later. He himself died on the 5<sup>th</sup> February 1804 aged seventy-one and is buried in Northumberland where his house has now been turned into a museum.

Priestley should be included in any pantheon of scientists. The bicentenary of his death is an opportune time to reassess his life and work and several events are planned during the year. He possessed enormous scientific skills and originality of thought as well as having the courage to promote unpopular views. He was a man of rare insight and talent.

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## HERBERT FRÖHLICH FRS

*A physicist ahead of his time*

To mark the centenary of the birth of Herbert Fröhlich, (9th December 1905), an International Symposium will take place in Liverpool. Fröhlich was the first holder of the Chair of Theoretical Physics at The University of Liverpool from 1948 until his retirement in 1973 and Professor Emeritus until his death in 1991.

This Symposium is sponsored by:

**The University of Liverpool  
The Deutsche Forschungsgemeinschaft  
The Friends of Liverpool University  
The Institute of Physics**

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**Aim:**

The aim of the Symposium is to bring together physicists and biologists – particularly those who either knew Fröhlich personally or collaborated with him at some stage during his long and illustrious life – not only to reflect on past glories but to also to evaluate the impact of his legacy on present developments in Physics and Biology.

To this end, invited speakers will cover the different fields in which Fröhlich contributed so significantly to our understanding, thereby influencing future developments. During the Symposium there will be an exhibition of photographs and other memorabilia, including Fröhlich's most influential papers and books.

**Venue:**

The Symposium will be held in the historic Liverpool Medical Institution building, situated close to the University precinct. The venue has car parking, disabled access and a hearing loop.

**Tuesday 4<sup>th</sup> April 2006**

- 12 noon      Arrival and registration desk open.  
Liverpool Medical Institution, 114 Mount Pleasant,  
Liverpool, L3 5SR
- 1.00pm      Buffet lunch
- 2.00pm      **Welcome & Introduction**  
*Professor Drummond Bone*  
*Vice Chancellor, The University of Liverpool*
- 2.15pm      **Herbert Fröhlich Centenary Lecture**  
**Herbert Fröhlich FRS – A physicist ahead of his  
time**  
*Gerard J Hyland University of Warwick /*  
*International Institute of Biophysics, Neuss–*  
*Holzheim*
- 3.15pm      **A Coherent Walk in Solid-state Physics**  
*Hermann Haken – University of Stuttgart*
- 4.15pm      Tea
- 4.45pm      **Dielectrics in High Fields**  
*James H Calderwood – Trinity College, Dublin /*  
*University of Bolton*
- 7.15pm      **Symposium Dinner**  
  
**After Dinner Speeches**

### Wednesday 5th April 2006

- 9.00am     **On the Interplay between Micro and Macro Physics in Statistical Mechanics**  
*Geoffrey L Sewell, Queen Mary, University of London*
- 10.00am   **Fröhlich's One-dimensional superconductor or Charge-density wave?**  
*Charles G Kuper, Technion - Israel Institute of Technology, Haifa*
- 11.00am   Coffee
- 11.30am   **Herbert Fröhlich and Particle Physics**  
*Christopher Michael – The University of Liverpool*
- 12.00pm   Buffet Lunch
- 1.30pm     **Fröhlich's Coherent Excitations from the point of view of Quantum Field Theory.**  
*Hans-Peter Dürr, Max Planck Institute, Munich*
- 2.00pm     **Biology as seen by Fröhlich**  
*Cyril W Smith, University of Salford*
- 2.30pm     **Fröhlich Modes and Biological Function**  
*Fritz-Albert Popp, International Institute of Biophysics, Neuss-Holzheim*
- 3.00pm     **The role of Fröhlich's Coherent Excitations in Cancer Transformation of Cells**  
*Jiri Pokorny, Czech Academy of Sciences, Prague*
- 3.30pm     **Non-Linear Dynamics in Living Systems**  
*Friedemann Kaiser, University of Darmstadt*
- 4.00pm     Tea                      Close of Symposium

**Fee:**

The Symposium Fee is £60, if paid before 24 February 2006 (increasing to £70 thereafter), and includes morning and afternoon refreshments, lunches, the Symposium Dinner and a copy of the Proceedings/Festschrift.

**Hotels:**

Special University rates have been negotiated at 3 nearby hotels (*Adelphi, Feathers and Hope Street Hotels*).

For further details, please contact:

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<http://www.liv.ac.uk/physics/frohlich/>



## **Boltzmann's Legacy**

An International Symposium at the  
Erwin Schrödinger Institute for Mathematical Physics

In commemoration of Ludwig Boltzmann's death on September 5, 1906.

Wednesday, June 7 to Friday, June 9, 2006  
Erwin Schrödinger Institute, Boltzmannngasse 9, 1090 Vienna

Organizing Committee: G. Gallavotti, A. Kupiainen, W.L. Reiter,  
K. Schmidt, J. Schwermer, J. Yngvason

This Symposium is dedicated to Boltzmann's lasting legacy in kinetic theory, thermodynamics and statistical mechanics, and to his influence as a philosopher of science. A series of lectures will outline some recent developments in physics and mathematics related to Boltzmann's work as well as his influence from the point of view of history and philosophy of science.

The following speakers have confirmed their participation:

E.D.G. Cohen, Rockefeller University, New York  
Nadine de Courtenay, CNRS, Paris  
Christoph Dellago, Universität Wien  
Giovanni Gallavotti, Università di Roma 'La Sapienza'  
Oskar E. Lanford III, ETH Zürich  
Joel L. Lebowitz, Rutgers University  
Elliott H. Lieb, Princeton University  
Donald S. Ornstein, Stanford University  
Jurgen Renn, MPI für Wissenschaftsgeschichte, Berlin  
David Ruelle, IHES, Bures-sur-Yvette  
Peter Schuster, Universität Wien  
Herbert Spohn, TU München  
Cédric Villani, ENS Lyon  
Anton Zeilinger, Universität Wien

Further details at: [www.esi.ac.at/activities/Boltzmann2006.html](http://www.esi.ac.at/activities/Boltzmann2006.html)

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