CECIL EDWIN HENRY BAWN
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Elected FRS 1952

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Cecil Bawn was a physical chemist with particular expertise in chemical kinetics. Early in his career he made pioneering studies of free radical reactions in the gas phase and, during the war years, on the chemistry of high explosives. From mid career, he was one of the pioneers of polymer chemistry and established and led a strong and diverse group of polymer scientists at the University of Liverpool. He was a private and enigmatic person, with a strong sense of duty. His caring and helpful attitude was greatly appreciated locally by his students and younger faculty members. Nationally, he made outstanding service contributions to physical chemistry and polymer chemistry.

EARLY LIFE AND EDUCATION

Cecil Bawn was a Bristolian. He was born on 6 November 1908 to parents Edwin (b. 1877) and Lottie Alice (b. 1886, née Bright) Bawn, both of whom were born in Gloucestershire, England, and lived all their lives there. Cecil was educated in Bristol, attending the Cotham Grammar School and then the University of Bristol. He graduated with a BSc in chemistry in 1929 and stayed in Bristol for his postgraduate studies.

EARLY RESEARCH AT THE UNIVERSITY OF BRISTOL

Cecil carried out his PhD research at the University of Bristol under the guidance of Professor William E. Garner (FRS 1937), who held the Leverhulme Chair of Physical and Inorganic

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Chemistry there from 1927 to 1955. Garner had very broad interests in chemistry, and Cecil Bawn soon developed a similar outlook (17)*.

Garner had carried out his PhD research in organic chemistry with P. F. Frankland FRS in Birmingham, before moving to Göttingen in 1913 to study with Gustav Tammann, an expert in inorganic and physical chemistry. He left Göttingen, very hurriedly, at the outbreak of the First World War and spent the war years at the Woolwich Arsenal, working with Robert Robertson (FRS 1917; KBE 1918) on the calorimetry of high explosives. In 1919 Garner joined the academic staff at University College London (UCL), and began his research on heterogeneous catalysis and surface chemistry, kinetics of explosive reactions in gases and the ionization and radiation from flames. He collaborated with F. G. Donnan FRS, who was professor of physical chemistry, on membrane chemistry during that period. Garner continued all these studies after his move to Bristol, and Cecil Bawn worked with him on the oxidation of carbon monoxide.

The Garner group found that the radiation of the carbon monoxide flame could be decreased by the addition of small amounts of hydrogen. Cecil Bawn studied the catalytic effect of hydrogen on the carbon monoxide oxidation using vessels with different surface coatings. He used quartz, silvered quartz, aluminium, bronze and copper surfaces, and concluded that differences could be correlated with the thermal conductivity of the walls and that the key effect was the rate of removal of hydrogen atoms from the gas phase by the different surfaces (1). His proposed chain mechanism is given below; M is a reactive atom, originating from the firing plug used to initiate the flame, which initiates the chain reaction, and the termination step is the removal of hydrogen atoms by surface reaction.

\[
\begin{align*}
H_2 + M & \rightarrow 2H_\cdot + M \\
H_\cdot + CO + O_2 & \rightarrow CO_2 + HO_\cdot \\
HO_\cdot + CO & \rightarrow CO_2 + H_\cdot
\end{align*}
\]

**Victoria University of Manchester, 1931–1938**

Cecil Bawn was now an expert in physical chemistry and chemical kinetics, and he spent the next several years most productively in Manchester, first as an ICI fellow and later as a lecturer. Initially, he worked primarily on the oxidation chemistry of carbonyl sulfide and also collaborated with Walter Lochte-Holtgreven on its photochemistry and thermochemistry (2). Lochte-Holtgreven was in Manchester from 1930 to 1933 as a postdoctoral visitor, mostly working with W. H. Bragg FRS on spectroscopy. He returned to Germany and had a distinguished career at the Christian Albrechts University in Kiel.

Two life-changing events for Cecil Bawn took place in 1933 and 1934. In 1933, Michael Polanyi (FRS 1944) was appointed to a professorship in physical chemistry in Manchester. Cecil Bawn never co-authored a paper with Polanyi, but he was greatly influenced by him and by the many outstanding researchers who came to work with him over the next few years. Polanyi had held a professorship in Berlin, but was nervous about the rise of the Nazi party in Germany in 1933 and so the timing of the offer from Manchester was ideal. Polanyi was a magnet for outstanding researchers, and two of his students, Eugene Wigner (ForMemRS 1970) from the Berlin days and Melvin Calvin (ForMemRS 1959) from Manchester, as well

* Numbers in this form refer to the bibliography at the end of the text.
as his son, John Polanyi (FRS 1971), later became Nobel laureates. The second life-changing event was his marriage in 1934 to his Gloucestershire sweetheart, Winifred Mabel Jackson. In time, Winifred and Cecil had three children, two sons and one daughter. So both personally and professionally, this was a golden period.

Cecil Bawn played an invaluable role in helping Polanyi’s new students to get established, while broadening his own interests in chemical kinetics with advice from Polanyi. For example, he contributed to kinetic theory, including transition state theory and kinetic isotope effects as well as assessing the role of steric effects in associative chemical reactions. Experimentally, he began a distinguished series of papers investigating the reactions of sodium atoms in the gas phase (3, 4). This was technically demanding since the reagents needed to be prepared and purified in situ, followed by controlled mixing, measurement of the rates of reaction and analysis of the products. This can perhaps best be illustrated by the mostly glass apparatus constructed for studying the reaction of sodium atoms with HCl and DCl (figure 1) (3). The primary reactions gave hydrogen or deuterium atoms:

\[
\text{Na} + \text{H-Cl} \rightarrow \text{NaCl} + \text{H}.
\]

\[
\text{Na} + \text{D-Cl} \rightarrow \text{NaCl} + \text{D}.
\]
The related reactions of atomic sodium with alkyl halides were often accompanied by chemiluminescence. The primary products were alkyl radicals, which were formed in the absence of solvents so that their self-reactions could be studied. Primary alkyl radicals could dimerize or disproportionate (figure 2). Dibromomethane gave methylene (carbene), which could dimerize to ethylene or disproportionate to give methane. In the presence of hydrogen, methylene could insert into the H-H bond to give methane. Higher dihaloalkanes gave biradicals that could cyclize or undergo hydrogen atom migration or C-C bond cleavage to give alkenes. For example, trimethylene biradical gave a mixture of cyclopropane and propene, while tetramethylene biradical could give two equivalents of ethylene. The kinetic parameters for many of these reactions were elucidated (4). Alkyl radicals were becoming known as intermediates in many reactions, including polymerization and combustion, so these fundamental studies had considerable impact.

UNIVERSITY OF BRISTOL AND THE ARMAMENT RESEARCH DEPARTMENT, 1938–1948

In 1938, Cecil Bawn was invited by William Garner to return to his alma mater, the University of Bristol, as lecturer in physical chemistry. He accepted and quickly set up to continue his studies in chemical kinetics. However, this plan was soon waylaid by the outbreak of the Second World War. Garner and Bawn organized a major team of researchers at the university to support the Government Ordnance Factories in explosives and munitions research. Garner moved to Fort Halstead in Kent in 1943 to become superintendent of Chemical and Explosives Research for the Ministry of Supply, and later became chief superintendent of Armament Research. Cecil Bawn was seconded to this effort and became principal scientific officer in the Armament Research department. He carried out valuable research on explosives and pyrotechnics, especially on improving safety during their manufacture. Personally, he studied the kinetics of the decomposition of explosives and developed special techniques for doing this safely. He also liaised with many university- and industry-based research groups who were recruited to this war work.
In the early war years, Garner and Bawn worked closely with Godfrey Rotter (CB, CBE, GM), who was director of explosives research at Woolwich from 1921 to 1942. Rotter was the leading expert in explosives research at that time, having served as a researcher in both world wars. After his formal retirement, Rotter continued to serve in an advisory capacity. (Later, in 1945, following an explosion in a mine shaft used to store ammunition, he showed great personal heroism as he volunteered to supervise the removal of a large quantity of unexploded munitions under most dangerous conditions. He was awarded the George Medal for this act of bravery.) The research carried out during these war years was highly classified and much of it was never published. However, much later, Bawn and Rotter edited a two volume publication, Science of explosives, whose chapters summarized much of the war-time research carried out by individual units under their guidance (13).

When the war finally ended, Cecil Bawn continued as a member of the Scientific Advisory Council of the Ministry of Supply as he returned full time to the University of Bristol. He was promoted to reader in 1945 and decided that it was an appropriate time to reassess his research priorities. He continued his research in gas phase kinetics, combustion and free radical chemistry (4), but he also began to develop new interests in solution chemistry, polymer chemistry and solid state chemistry. Most notably, he gave a lecture course on polymer chemistry to postgraduate students at Bristol and then developed his notes into book form. The book, The chemistry of high polymers, was published in 1948 by Butterworths in the UK and by Interscience in the USA (5). The text was aimed at students and industrial chemists beginning research in polymer chemistry. It covered all main areas of polymer synthesis, characterization, structure, properties and applications that were known at that time. The book said just the right thing in the right way at the right time, as the field of polymer chemistry was beginning a period of explosive growth. There were other more specialist books on individual classes of polymers, but none that covered the whole field in such a comprehensible manner. As a result, Cecil Bawn’s book was an immediate success and many editions were published over the next 10 years.

When this classic book was still in its publication stage, Cecil Bawn was already planning his next and final academic move to the University of Liverpool. This meant parting from his inspirational mentor, William Garner, and his beloved University of Bristol. However, there was one noteworthy later connection. In 1955, Garner retired and, to mark the occasion, edited a book, Chemistry of the solid state, with many of the chapters written by his former students. Cecil Bawn’s chapter was entitled ‘The decomposition of organic solids’, and was related to his war-time research on explosives (12). Many of Bawn’s reviews contained original material and this was no exception. He developed a kinetic scheme to explain the sigmoidal curves that described the rate of decomposition of solids accompanied by melting. Such decomposition reactions could often be described as:

\[ \text{A(solid)} \rightarrow \text{B(liquid)} + \text{C(gas)}. \]

If compound A is partially soluble in the forming liquid B and if, as is usually the case, the rate of decomposition of A in solution is much faster than in the solid state, then the rate of decomposition at a fixed temperature just below the melting point of compound A will increase rapidly as the reaction proceeds, leading to the observed sigmoidal curve. Much later, this model had considerable impact when it was realized that it often applied to the decomposition of pharmaceutical compounds, and it was termed the ‘Bawn model’ or ‘Bawn kinetics’ (Brown & Glass 2003).
Cecil Bawn moved to the University of Liverpool in 1948. The family settled across the Mersey in the Prenton area of Birkenhead, and he kept a carefully tended garden there. His initial appointment was as Grant–Brunner Professor of Inorganic and Physical Chemistry, succeeding William Lewis FRS. He also became head of the Department of Inorganic and Physical Chemistry, with organic chemistry being a separate department at that time.

In 1969 the Grant–Brunner chair was split; Bawn then became the Brunner Professor of Physical Chemistry while Ken Holliday became the Grant Professor of Inorganic Chemistry. Cecil Bawn remained as Brunner Professor and head of department until his retirement in 1973. Early in his tenure at Liverpool, a new building was designed and constructed to house the growing research in chemistry. It was opened in 1954 by the Duke of Edinburgh. The impressive new edifice was called the Donnan Laboratories after F. G. Donnan, who had served as the first Brunner Professor of Physical Chemistry from 1906 to 1913, before moving to UCL. Recall that he had influenced Bawn’s mentor, W. E. Garner, at UCL, so completing a chemical circle of outstanding physical chemists.

Charles Tipper, who had recently completed his PhD with Cecil Bawn in Bristol, accompanied him to Liverpool as lecturer in physical chemistry and continued research on oxidation chemistry in both the gas phase and solution (4, 7). Bawn himself directed kinetic studies in solution, including reactions that could form radicals that were useful for initiating polymerization. He reported the dissociation to free radicals of such compounds as dibenzoyl peroxide, azobisisobutyronitrile and persulfate ions (8, 11). He also complemented his earlier research on oxidation in the gas phase by studying the mechanisms of oxidation of organic compounds in solution. For example, he studied the transition metal catalysed oxidation of aldehydes, alcohols and alkenes, especially with cobalt(III) (9).

In parallel with the kinetic studies, Cecil Bawn made careful measurements of the thermodynamic and colligative properties of polymer solutions, including vapour pressure, osmotic pressure and viscosity in several solvents (6, 10). However, following the discovery of the heterogeneous Ziegler–Natta catalysts, from 1953 to 1955, his main theme was the study of new soluble catalysts and initiators of polymerization to make stereoregular polymers (12, 16). A planar alkene \( \text{CH}_2=\text{CHR} \) is called prochiral, and its polymer -\( (\text{CH}_2-\text{CHR})_n \) contains chiral -\( \text{CHR}- \) groups, which may be randomly oriented (atactic), have alternating chirality (syndiotactic) or have the same chirality throughout (isotactic), and the polymer properties depend on the tacticity and degree of stereoregularity. Some unusual forms of polymerization were discovered in the process of trying to make more stereoregular polymers. For example, Tony Ledwith (FRS 1995) (Feast 2018) found that diazoalkanes could be polymerized by BF3 or EtCu giving living polymers and so allowing block copolymers to be prepared (15, 18). However, the reagents are expensive and the stereoregularity was not high enough to be useful.

\[
\begin{align*}
\text{BF}_3 + n\text{CH}_2\text{N}_2 & \rightarrow \text{F}_2\text{B}-(\text{CH}_2)_n-\text{F} + n\text{N}_2 \\
\text{F}_2\text{B}-(\text{CH}_2)_n-\text{F} + x\text{RCHN}_2 & \rightarrow \text{F}_2\text{B}-(\text{CH}_2)_n-(\text{CHR})_x-\text{F} + x\text{N}_2.
\end{align*}
\]

Cecil Bawn’s group members were able to prepare alkyl derivatives of several transition metals, usually by alkyl exchange reactions with organoaluminium or organolead compounds, including RTiX3, RCu and RAg (R = Me, Et, Ph), and to study their ability to initiate...
polymerization of prochiral alkenes of several types (14–16, 20) (North 1960). In these
days before dissymmetric single site catalysts were discovered, the stereoselectivity was
determined by end group control. Selectivity was expected to be highest at low temperature,
and so the most active initiators were needed to allow polymerization under these conditions.
Even the free radical polymerization of methyl methacrylate at $-30^\circ\text{C}$ occurred with
reasonable stereoregularity (16, 18).

After his initial burst of activity as he established his research group in Liverpool, Cecil
Bawn was drawn more into external service and consulting, and his students and postdoctoral
fellows necessarily became self-sufficient as they saw him only for general guidance and
advice. Towards the end, he mostly collaborated with Tony Ledwith, when the joint projects
required the Bawn expertise in chemical kinetics. This often involved polymerization using
cations, cation radicals or anions as initiators (21, 22). Cecil Bawn still followed the advances
in all areas of polymer science and, because he also had a reputation for being able to describe
complex technical matters in understandable form, he was often called on to write or edit
progress reports on polymers and polymerization for both specialist and lay audiences (16,
19, 23, 24). Alastair North, who, following his periods in Liverpool and Strathclyde, was
president at the Asian Institute of Technology, gives the following account of working with
Cecil Bawn (personal communication). Many will recognize the accuracy of the description
of Bawn’s modus operandi.

I joined the Department of Cecil Bawn in 1958 to work with him as an ICI Fellow. When I arrived
he checked that my domestic arrangements were in order and said that he wanted me to work on
the kinetics of Ziegler polymerization. At the time he was very involved in Royal Society and
other work outside the department so he left me alone to decide what I would do and how I would
do it.

At that time all previous kinetic studies of Ziegler polymerization had involved a
heterogeneous system. That made kinetic analysis of the various reaction steps almost impossible.
So I decided to see if titanium and aluminium compounds soluble in organic solvents could
polymerize a common monomer like styrene. I built the apparatus to do the kinetic work and
reported to the boss what I was doing. He praised my efforts and told me to go ahead. After that,
for several months, the only times I saw him were when he brought visitors round the lab and
proudly showed them my highly coloured polymerization solutions. After a year I completed the
work, wrote it up and gave it to the prof. He praised it, submitted it to the Proceedings of the
Royal Society (North 1960) and gave me a job as lecturer.

In the selection committee for that job I got my first view of his power in the university.
It turned out that he wanted to appoint a radiochemist, Dr. Gordon Hughes, to build up the
radiochemistry section. But he was also impressed by myself and a shock-wave chemist from
Harvard, the late Prof. John Bradley. So he persuaded the committee to appoint all three of us.
Those were the days!

When I started as a lecturer, he urged me to follow my own interests in the kinetics of diffusion-
controlled free radical solution polymerization, but took no part in the work. These interests in
polymer molecular motion led me to realize that while Liverpool was very well established in
polymer chemistry, it had no presence in the more physical side of polymer science. I discussed
this with Cecil Bawn and he encouraged me to embark on dielectric and ultrasonic studies of
polymer molecular motion. To this end he obtained considerable grants for the purchase of all the
necessary equipment and converted a little-used teaching laboratory for the work.

Typical of his generous support, when I was appointed to the chair of Physical Chemistry at
Strathclyde he allowed me to take the equipment to continue my work there.
So I always found him to be a very charming, supportive boss. The fact that he did not involve himself in the details of my work did not in any way detract from my admiration of his wider, wiser view of what was important in the progress of polymer science research. In that, I learned far more from him than simply what molecules were doing.

Geoff Eastmond, who had been a student at Liverpool and returned as lecturer after a period with Courtaulds, recounts how Cecil Bawn assisted him in taking up a Leverhulme Visiting Fellowship to allow him and his family to visit Kyoto, Japan, for the academic year 1970–1971, at a critical time when he was planning a change in research direction. This was typical of Bawn’s support for all his younger faculty members as well as for his own students.

Cecil Bawn steadily built up the polymer group in Liverpool, initially by appointing members of his own research group, Don Margerison, Tony Ledwith and Alastair North. In 1962, an opportunity came to make a major expansion when Courtaulds was taken over and the new owners decided to close the Fundamental Research Laboratory in Maidenhead. C. H. (Bam) Bamford (FRS 1964) had served as the head of this laboratory and Cecil Bawn was able to recruit him as Campbell Brown Professor of Industrial Chemistry. He moved to Liverpool with two of his colleagues, Harry Block and Geoff Eastmond, and continued his outstanding research on free radical polymerization and related topics. The department was renamed the Department of Inorganic, Physical and Industrial Chemistry. After Alastair North moved to Strathclyde, Steve Walker was appointed and collaborated with Harry Block in studies of dielectric relaxation and rheology of polymers. Meanwhile, Geoff Eastmond worked on the synthesis, properties and applications of polymers, especially poly(ether imide)s. The polymer group was flourishing when Cecil Bawn retired in 1973.

**EXTERNAL SERVICE AND HONOURS**

Cecil Bawn was awarded the Tilden Prize in 1948, the year that he moved from Bristol. Higher honours were to follow as he was elected FRS in 1952. Senior academics are not immune from making errors and, amusingly, the name on the certificate is given by his distinguished proposers as Cecil Edward Henry Bawn with a later manuscript note ‘on election found to be Edwin’. In 1956–1957, he served as a member of council of the Royal Society. Cecil was appointed CBE in 1956, based on his service as Grant–Brunner professor and his war service. Later honours included the Liversidge Award for physical chemistry in 1962, the Swinburne Gold Medal in 1966 and several honorary degrees.

Cecil had served as adviser to the Ministry of Supply since the war ended. He was persuaded to be the second chairman (following Geoffrey Gee) of its Joint Services (Materials) Advisory Committee, and he served in this demanding role for a decade. Concurrently, he served as a member of the University Grants Committee from 1965 to 1974, and he was president of the Faraday Society from 1967 to 1968.

Two service projects to promote polymer chemistry deserve a special mention here. Cecil Bawn was a founding member of the British High Polymer Research Group (HPRG), formed following a successful International Union of Pure and Applied Chemistry meeting in 1958, along with fellow academic polymer scientists Sir Harry Melville FRS (1908–2000), John Bevington (1922–2007), Fred Dainton FRS (Baron Dainton of Hallam Moors, 1914–1997) and Geoffrey Gee FRS (1910–1996), with generous financial support from industry members. The HPRG organizes an annual conference on topical areas in polymer science.
and engineering, with attendance by invitation only. Until 2003 the conferences were held at a hotel in Moretonhampstead in Devon, remote from the nearest town; thus, discussion and conversation were fostered among the diverse group of invited academic and industrial polymer scientists and engineers. Of course, there were some rural diversions, including fishing, golfing and the local village pub. This annual conference was keenly anticipated by the Liverpool polymer groups, and Cecil Bawn was a regular attendee, often accompanied by Winifred. The conference site was close to his retirement home in the village of Stoodleigh, near Tiverton in central Devon, so he continued to attend after retirement up until the year of his death (also the last Moretonhampstead conference).

At the same time, and with a similar group of founding members, the journal *Polymer* was established, with the first papers published in 1959. The initial editors were Cecil Bawn, Geoffrey Gee (University of Manchester), C. H. Bamford (then at Courtaulds Research) and Rowland Hill (ICI Fibres). Cecil Bawn, in his final publication (24), wrote the editorial for the twenty-fifth anniversary volume and his introduction included the following section:

The study of high polymers is a relatively new branch of science, since it was not until the 1930s that the true nature of the polymer molecule was firmly established. In Europe the expected development of the subject was greatly impeded by World War II, but as soon as conditions in the Universities returned to normal, work in the field of polymers vigorously accelerated. In the United Kingdom research expanded rapidly in both the Universities and Industry, and the new branch of science which emerged was not readily accepted or recognized by the learned societies which had a virtual monopoly of publication. The subject was so important and its growth potential so immense that a suitable medium was necessary to cope with the growing volume of somewhat specialized publications. It was for this reason that a small group of leading scientists in the Universities and in Industry got together with Butterworths, a leading publishing house of legal and medical books and journals, which had recently entered the scientific publishing business, to found a new scientific journal devoted to all aspects of polymer science. The name POLYMER was chosen for the new publication, and starting from small beginnings, today the journal has become one of the world’s leading publications on the subject, and with an internationally respected reputation.

While on the topic of polymer literature, it is appropriate to end this account by noting that Tony Ledwith and Alastair North edited the book *Molecular behaviour and the development of polymeric materials* as a tribute to Cecil Bawn on the occasion of his retirement. Many of the chapters were written by Cecil Bawn’s scientific children and grandchildren, and the book is a fitting tribute to one of the pioneers of polymer science (Ledwith & North 1975).

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Dick Puddephatt OC, FRS, FRSC* is distinguished university professor emeritus at the University of Western Ontario. He was educated in chemistry at University College London, where he carried out PhD research with Alwyn Davies (FRS 1989) and Robin Clark (FRS 1990). After a teaching postdoctoral fellowship with Howard Clark at the University of Western Ontario, he was appointed as lecturer at the University of Liverpool during the time when Cecil Bawn was head of the Department of Inorganic, Physical and Industrial Chemistry. Eight years later, he moved back as professor to the University of Western Ontario. His research interests are in organometallic and coordination chemistry with applications in catalysis and materials science.

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