ARTHUR JOHN BIRCH

3 August 1915 – 8 December 1995

Elected FRS 1958

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Arthur John Birch, AC, CMG, FRS, FAA, FRACI, was one of the great masters of organic chemistry of the twentieth century. His extraordinary creativity left its imprint across the breadth of the subject in its broadest sense, from synthesis to biochemistry to organometallic chemistry. He remains best known for the reaction which bears his name, the Birch reduction of aromatic compounds by solutions of sodium and ethanol in liquid ammonia. This process has wide application most notably in the commercial synthesis of oral contraceptives, giving rise to his being called "the father of the pill", although he himself preferred the more remote "grandfather" relationship. His polyketide theory, which accounts for the biosynthetic origins of a wide range of natural products, is less widely acknowledged today simply because it has become absorbed into the accepted knowledge base of the subject. His final researches on the use of diene iron tricarbonyl derivatives in synthesis are equally distinguished, and have prompted others to extend their application. During his career he was involved in the design of three new university chemistry buildings, one of which now bears his name, and contributed influential advice to governments on national science policies.

The authors of this memoir knew Arthur Birch from complementary perspectives. Rod Rickards was as an undergraduate at Sydney University when he first met him in 1954, on a crowded evening tram going home down George Street. Banter with a fellow student suggested that the unknown Professor of Organic Chemistry was quite a lad, who worked on things like sex hormones. A quiet voice alongside them said, "You want to be careful what you say on these trams, you never know whom you are sitting next to." It was immediately apparent who sat alongside them. The Professor was undoubtedly more amused than the petrified students, and at a post-retirement symposium in his honour in Canberra in 1981 Birch recounted the incident with glee. In between these events Rod attended Birch's undergraduate lectures, became one of his research students initially in Sydney and then in Manchester, and one of his staff in Manchester and Canberra. Finally he had the sad honour of speaking at his funeral.

John Cornforth was a year behind Birch at Sydney University and followed him to Robinson's laboratory at Oxford. He married Rita Harradence, Birch's contemporary at Sydney, who also went to Oxford one year after Birch. The three were lifelong friends.

EARLY YEARS

Arthur Birch was born in Sydney on 3 August 1915, the only child of Arthur Spencer Birch and Lily Bailey. His father was born in Northamptonshire, England, left school at 12 and home at 14, and then lived in Canada, Fiji, and New Zealand where he met Lily. Lily was born in central Tasmania, but had emigrated to New Zealand at 27, and was 37 when they married. Arthur was born a year later, after the couple moved to Sydney. His father became pastry chef at a major Sydney hotel, and later manager of Woolworth's cafeterias. Arthur "sauntered carelessly through primary school" in the suburb of Woollahra, but became interested in science. His father encouraged this with some apparatus and books bought with a legacy from an aunt, and Arthur "taught himself organic chemistry" from about the age of 12. With his father now ailing, he was selected to go to the renowned Sydney Technical High School, where he did well academically while pursuing his own initiatives.

Chemistry initially fascinated him aesthetically rather than intellectually, although in later years he was clearly moved by the intellectual "highs" which came from being the first to see and understand fundamental truths of chemical and biological behaviour. The beautiful natural product chemistry of the Australian bush intrigued him, with its range of odours from eucalypt trees, brilliant flower colours, and strange coloured resins exuding from the trunks of eucalypts and grass trees. He was to return to all these themes in due course as a scientist.

CAREER PATH

Sydney 1933-1938

Sydney University, the oldest in Australia, was then the only university in the state of New South Wales, with about 3000 students. Its first Professor of Organic Chemistry was Robert Robinson from 1913 to 1915. In his final school examination in 1932 Arthur Birch was ranked third in Chemistry in the state, winning a Public Exhibition exempting him from university fees. His rivals included Rita Harradence, later to become Lady Cornforth, who topped the state. These were the years of the Depression. His father was declining and died in 1937, so his family could offer him little more than accommodation. To pursue his desire to learn he washed bricks, coached other students, and won the only scholarship available at the end of his first year. The Sydney Chemistry Department in the 1930s lacked resources and ready access to the international chemical world, but its undergraduates were rich in talent and made their own fortunes. Birch's competition with Rita Harradence continued, and on graduation at the end of their Honours year in 1936 they were to share the University Medal in Chemistry. Ern Ritchie (later Professor at Sydney University)

was in the same year, Allan Maccoll (Professor at University College, London) was a year ahead, and a year behind were John Cornforth (Nobel Laureate) and Ron Nyholm (also Professor at University College, London).

Birch's formal entry into research began in his fourth year, the Honours year in the Sydney system. His Honours and M.Sc. Supervisor, Professor J. C. Earl, gave him a bottle of *Eucalyptus dives* leaf oil, a by-product of piperitone production, and then went on sabbatical leave. The result was five publications, four with Birch as sole author, on monoterpene natural products. The schoolboy's interests were bearing fruit. In 1938 he was awarded a scholarship of the Royal Commission for the Exhibition of 1851 to study for a doctorate degree in England. There were no Ph.D. degrees awarded in Australia then, and few opportunities for those with such degrees, so he chose to work with Robert Robinson in Oxford and sailed from Sydney as World War II developed in Europe.

Oxford 1938-1948

Birch's ten years at Oxford, 1938-1948, were not normal years for anyone alive at that time. A letter from him, written shortly after he started work at the Dyson Perrins Laboratory (DP), expressed pleasure at the ready availability of chemicals and disgust at the quality of the apparatus and equipment. Robinson had given him a problem of synthesis based on a speculation, later found to be baseless, that the peculiar lipids of mycobacteria contained fatty acids doubly branched at the positions next to the carboxyl group. Methods for the preparation, separation and handling of such compounds were largely undeveloped at the time. Birch did a creditable job with the preparation and gained his D.Phil. from the work in 1940. He never worked with fatty acids again. His pre-doctoral years were darkened by the approach and outbreak of the war in Europe.

Oxford was never bombed and workers in the DP shared the life of most civilians in Britain: the blacked-out nights, the multifarious shortages and the resulting queues (even for films), the nutritionally adequate but uninteresting food (someone mistranslated the motto *Alchymista spem alit aeternam* above the DP entrance as "Eternal Spam nourishes the chemist") and, for the first two years and more, the increasingly ominous news. In practice, people adapted: finding, for example, the Zionist restaurant that could make boiled red cabbage palatable by cooking it with vinegar and a little spice, or the pub that sporadically dispensed draught cider. Birch joined the Home Guard ("Dad's Army"); his autobiography (18) comments on it with characteristic wry humour.

Robinson was soon involved with numerous committees directing the contribution of science to the country's war effort. He could not devote much time to his students and he had no deputy. This meant that students were unusually free to follow their own ideas: excellent for those who could think for themselves and learn from their work and from interaction with able peers, but less so for those who expected to be taught.

In about 1941 Birch was focussed on steroid synthesis. At the time Birch was technically an employee of ICI (Imperial Chemical Industries, Ltd.), through which a government grant was funnelled. Birch was required to submit work to ICI for consideration of patenting before publication. Birch was supposed to have been making simple steroid analogs but was intrigued by the idea of the total steroid synthesis. Birch ran into difficulties as Robinson tried to divert him from pursuing his synthetic ideas and would not supply him with the then very expensive estrone starting material.

This work led to perhaps the most significant achievement of Birch's career. At the time chemical methods could be used to make specifically substituted polycyclic aromatic compounds, which might conceptually have been used to make the nucleus of steroid hormones. However, there were many problems to be solved such as partial reduction of such systems to provide functional groups as synthetic "handles". To achieve his goal of a synthetic hormone Birch needed to achieve the partial reduction of a monobenzene. A key clue to solving the synthesis was provided by the Cornforths who were then in Oxford. They reduced 2-methoxynaphthalene with sodium and alcohol into its dihydro derivative and realized that this derivative contained an enol-ether group and was convertible by acidic hydrolysis into 2-tetralone. Other ideas and observations also provided clues. One was the reduction by A. Windaus of ring a 3-methoxy-ring A,B-naphthalenoid steroid, although he had not interpreted the overall mechanism correctly.

In 1942 Birch considered that if this type of reduction could be brought about with a mono-benzenoid system, then synthesis should eventually yield the conjugated ketone required for 19-nortestosterone and other functionalized 19-norsteroids. Birch faced a number of experimental difficulties in that sodium and alcohols cannot generally bring about such hydrogenations with monobenzenoid derivatives. Birch surveyed the literature for partial reductions of monobenzenoid compounds and found that C. B. Wooster had fortuitously found that benzene, toluene, or methoxybenzene can be reduced into dihydro derivatives by a combination of sodium and ethanol in liquid ammonia. This procedure contrasted with no reduction by sodium and ethanol, or by sodium alone in ammonia. Birch followed the lead and a key result was the monobenzene-type reduction by the joint action of sodium and ethanol in the liquid ammonia. Birch first examined the reduction of methoxybenzene in January 1943. Birch recollected his delight when he added a little of his reaction product to a solution of dinitrophenylhydrazine in hydrochloric acid. A slowly developing crystalline yellow precipitate dissolved when the mixture was heated and was redeposited as beautiful orange-red crystals. That test-tube experiment said it all: the addition of hydrogen was necessarily to the 2- and 5-positions of methoxybenzene. The enol ether group was hydrolysed by the acid to cyclohex-3-enone and thence by slower isomerisation to cyclohex-2-enone, each of which formed its characteristic coloured derivative with the hydrazine. The Birch reduction was born. Birch spent much time despite Robinson's disapproval, exploring and developing the reaction.

Later in 1943 Birch reduced, as models, a number of simple substituted aromatic compounds, wrote a paper, and sent it to ICI for examination before publication. Birch was surprised by the response, because ICI had an agreement with DuPont, to

whom Wooster had assigned a patent with a condition that ICI stay out of this reduction field. Birch, however, pursued publication and Birch's initial results were published in 1944 but without mention of the steroid connection for a war-time security reason. The reaction was later named the "Birch reduction" by Carl Djerassi who later used the reduction process to make 19-norsteroids. With apparently reluctant support from Robinson Birch continued his work but with limited resources.

A breakthrough came in 1947, when Birch met Gilbert Stork following an IUPAC Congress and gave Birch five grammes of estrone. This was enough to make 19-nortestosterone via the precursor 5,7-unsaturated isomeric ketone. The work was assisted by S. M. Mukherji in 1948-1949. Birch had chosen to make a structurally relatively simple androgen with a 17-OH group, to test any biological activity of the proposed new synthetic 19-nor nucleus. In 1948 Birch sent his synthetic 19-nortestosterone and its ß,ɣ-unsaturated isomer to ICI for biological testing. However, it was withdrawn as Robinson had an agreement with Charles Dodds of the Courtauld Institute that all Oxford compounds would be tested there.

Birch published the synthesis before finding out that the products were biologically active, the former as an androgen (about 20-30% of testosterone) and the latter as an estrogen. Birch's 19-nortestosterone was the first totally synthetic highly active androgen and the first synthetic structure-specific steroid hormone. This work was published before the natural hormone syntheses of Woodward and of Cornforth and Robinson. Birch's work demonstrated for the first time a very marked hormonal activity of a highly structure-dependent type in an altered skeleton of normal stereochemistry. It provided a totally unique method to make the whole new 19-nor hormonal series. For a variety of reasons Birch did not patent the series or the method. In 1951 Carl Djerassi used a modified Birch reduction to produce 19-norprogesterone. Later in 1953 G. Pincus discovered oral contraceptive effects of progestational agents. These developments, among others, ultimately led to the oral contraceptive: "The Pill". Hence Birch's Australian description as "Grandfather of the pill".

Almost the last event of Birch's Oxford days was his marriage to Jessie Williams, an event seen by all his friends as the best thing that could have happened to him.

Cambridge 1949-1952

In January 1949 Birch moved to Cambridge University as Smithson Fellow of the Royal Society. This appointment carried prestige, reasonable remuneration, and an independence which unfortunately precluded him from receiving university research support other than through the generosity of Sir Alexander Todd, who was a good friend to Birch on several occasions and whose opinion Birch respected greatly, especially on administrative matters. Todd allocated him Herchel Smith as a PhD student, a fortunate event that would later have major ramifications. In contrast to Oxford, the Cambridge laboratory facilities were excellent, and they made good progress with steroid synthesis directed towards androgenic and progestational hormones.

By Birch's own admission, however, he was at that time becoming rather bored with synthesis, and the surrounding research projects of Todd and others reawakened his interest in natural products. Initially this found expression in deducing the correct structures of published natural products, and in collaborating with others to define the structures of new compounds. Much more significant for the subsequent development of organic chemistry, however, was his increasing interest in biosynthesis, the detailed process whereby natural products are formed by enzymes in living systems. This would become Birch's second major contribution to science.

Alone after her husband's death, Birch's mother Lily had followed him to Oxford in 1939. During the progressive development of Parkinson's disease, Birch had cared for her largely on his own, until the advent of Jessie Williams as her nurse in 1947. Lily Birch accompanied the newly married couple to Cambridge, and died there in 1951. In the same year he was invited to accept the Chair of Organic Chemistry at his alma mater, Sydney University, and with his wife's concurrence he decided to accept this challenge. After 14 years absence he was homesick for Australia, and it would be a better place in which to bring up their three young children than post-war Britain.

Sydney 1952-1955

In 1952 Birch returned to Sydney to take up his first tenured academic appointment, as Professor of Organic Chemistry and Head of Department in a Chemistry School of nearly 1000 students, with little teaching and less administrative experience. The Chair had been vacant for several years, even its continued existence the subject of university controversy. The Depression and War years had passed, but the Department still lacked resources and international contacts. The laboratories in sandstone buildings around the Vice-Chancellor's quadrangle ("the vice quad") were ancient and poorly equipped. Spectroscopy was limited to a manually driven UV spectrometer, and the small bottle of the novel solvent tetrahydrofuran could only be used if 90% could be recovered. The state government provided finance for a new building by mistake, confusing chemistry with pharmacy, but honoured its public commitment. This was the first of three such building designs with which Birch was to be involved, although the building itself was not erected until after his departure from Sydney in 1955.

The research projects chosen had to make the most of these facilities, in the hands of research students who mostly did only Honours or Masters degrees. Those who wanted to pursue a doctorate still usually went to England, although it was now possible in Sydney. Birch's classic publication on the biosynthesis of phenolic natural products, "Studies in Relation to Biosynthesis. Part 1", embodying ideas developed largely in Cambridge, was published by the Australian Journal of Chemistry in 1953 (3), having been rejected by the Journal of the Chemical Society on the grounds that it lacked experimental support. Proof of the hypothesis required the radiolabelled compounds which were now becoming available following developments in isotope technology during the War. With financial assistance from the Nuffield and Rockefeller Foundations to buy ^{14}C-labelled acetate and train students in its use, the first experimental support for the acetate hypothesis was presented in 1955. These students were shortly to follow their supervisor to England.

Birch also accomplished some structural work on natural products and some synthetic chemistry in Sydney, but the research environment was too restrictive. In 1954 he was elected a Fellow of the newly formed Australian Academy of Science. In 1955 he declined an offer of a foundation chemistry chair in the Research School of Physical Sciences at the new Australian National University (ANU) in Canberra. It would be 12 years before he joined the ANU, taking instead the renowned organic chemistry chair at the University of Manchester vacated by Professor E. R. H. Jones on his way to Oxford. His dissatisfaction on leaving Sydney in late 1955 prompted newspaper headlines like "Beggars in Mortarboards. Why the Professor Resigned." The departure for England of Birch and other senior chemists was a factor leading to the subsequent reorganisation of Australian universities under Commonwealth rather than State auspices and funding. Birch has dryly suggested that "I probably made my best contribution to the Australian university system by then publicly quitting it".

Manchester 1956-1967

Manchester was different. The Australian students who joined Birch in the industrial, commercial and cultural centre of northern England were used to the brilliant clear light and the sand and surf of their own country. They now frequently found themselves in thick, damp smog, at times barely able to see street lights glinting through the gloom at midday. They drank warm beer with the locals, learned to understand the North Country accent, watched Manchester United play football, and cheered the Australian cricketers at Old Trafford. Birch, too, liked the people, and the city because "it was easier to get out of than, say, London". But the "red brick" university dating back to 1851 was also different from Sydney, and its faculty lists which included Nobel Laureates reflected the illustrious scientific tradition that Birch felt honoured to join.

Birch's research flourished. In Cambridge he had realised that microorganisms rather than higher plants were the preferred vehicles for experimental biochemistry. They were prolific producers of the phenolic compounds in which he was interested, and could be grown readily in the laboratory. The Manchester Chemistry Department already had such a facility, established by Birch's predecessor E. R. H. Jones. He now appointed Herchel Smith, his Ph.D. student from Cambridge, to the lecturing staff, and they collaborated on biosynthetic research. Herchel learned and introduced radiotracer techniques, which dramatically accelerated the biosynthetic studies. Direct quantitative ^{14}C assay of compounds was carried out on open planchettes under an end-window Geiger counter, avoiding the cumbersome combustions to carbon dioxide gas and thus leaving the compounds available for further purification or degradative chemistry. The low counting efficiency was offset by the competence and convenience of the producing microorganisms.

Herchel Smith and Birch also resumed their Cambridge collaboration on sex-hormone synthesis, until Herchel wanted independence in this area and Birch withdrew. Herchel was highly successful, ultimately achieving an effective total synthesis of norgestrel and its analogues which were to become widely used constituents of modern oral contraceptives. The basic chemistry was carried out in Manchester, but

no patents were then filed. In 1961 Herchel moved to Wyeth Pharmaceutical Industries in Pennsylvania as Research Director, taking with him two Mancunian Ph.D. students who happened to be in the right place at the right time. Subsequent royalties enabled Herchel Smith to retire in 1973; at his death in 2001 his estate value was estimated in excess of £100 million. He generously bequeathed some £90 million to be shared between his alma mater Cambridge University and Harvard University, supplementing the £15 million given to Cambridge during his lifetime. Birch's work on the reduction of aromatic rings was crucial to this success, a fact that gave him intellectual satisfaction.

During this period Birch utilised intermediates prepared by his metal-ammonia reduction chemistry in several areas apart from the steroid work. On the one hand they were elaborated by various means to natural products, on the other they were reacted with metal carbonyls to provide the organometallic species which were to interest Birch until his retirement.

The old Manchester laboratories had been periodically extended since their opening in 1872, when they were considered the best in the country (Burkhardt 1954), and now had character and history but were outdated and inflexible. They were reasonably equipped with ultraviolet and infrared spectrometry, and the physical chemists might allow their mass spectrometer to be used for organic work if the sample was volatile. But organic chemistry was changing rapidly, with increasing dependence upon sophisticated instrumentation. Fortunately Associated Electrical Industries were making the world's best mass spectrometers only a few miles away, and their development engineers were happy to test the capabilities of instruments on their production line. In due course a new chemistry building was designed and built, and in its turn became the best equipped in the United Kingdom. Organic mass spectrometry became routine with the acquisition of the classic AEI MS 9 spectrometer. Proton nuclear magnetic resonance spectrometry was emerging from the realm of physics to revolutionise organic chemistry, so the government commissioned AEI to design and build NMR spectrometers to save England importing state-of-the-art American Varian instruments. After much delay the Department acquired one, which detected passing buses better than precessing protons and was superseded in the new building by a Varian A60.

The advent of such instrumentation changed the face of natural product chemistry worldwide. Birch's structural work in Sydney and initially in Manchester was primarily of the classical type, dependent upon microanalyses to indicate molecular formulae, reaction chemistry to establish functionality and to break structures apart, occasional use of UV or IR spectroscopy, and analytical reasoning. To this he had added his own requirement of biosynthetic rationality, at times convincing in itself. Mass spectrometry now defined precise molecular formulae and suggested structural fragments, while ^{1}H NMR spectroscopy looked directly at the intact molecule, mapping hydrogen atoms and their environments. Birch recognised the importance of these advances and ensured they were available, but was not one to tie himself to technology. Instead, once his biosynthetic hypotheses were firmly established by experiment on known compounds, he reversed the logic and used radiotracer incorporations *in vivo* to assist structure determination of unknown natural products.

This innovative although somewhat cumbersome approach was valuable in difficult cases, but was soon surpassed by the increasing power of NMR analysis alone. Much later with the availability of ^{13}C-labelled compounds the two techniques would successfully merge, until direct spectrometry again prevailed.

Birch was elected to Fellowship of the Royal Society in 1958, and became established as one of the world's leading organic chemists. Scientific conferences, connections with industry (notably Syntex in Palo Alto and Mexico City, and Roche in Basle), periods in Nigeria to establish research, and even the occasional family holiday drew him away from the Department, where research students jokingly appointed him to the BOAC Chair of Chemistry (after the national airline, the British Overseas Airways Corporation). A less sympathetic undergraduate referred to "the occasional smell of stale cigar smoke in a lift". Although not inclined towards overall university administration, he nevertheless promoted departmental interests, setting up and chairing the first Department of Biological Chemistry in Manchester.

One conference Birch attended was the 1st IUPAC Symposium on Natural Products, held in Sydney, Canberra and Melbourne in 1960. In Canberra the establishment of a Research School of Chemistry at the ANU was discussed, with Birch and Professors David Craig and Ronald Nyholm, now both at University College, London, as the three Foundation Professors. Craig had been a professorial colleague with Birch in Sydney, while Nyholm had been at the New South Wales University of Technology. This unique but onerous opportunity was ultimately accepted only by Birch and Craig; Nyholm, who was later knighted, decided to stay in England. Imaginatively code-named 'Project C' by the ANU to prevent premature exposure (Foster & Varghese 1996), the basic building was designed in a flat in Half Moon Street, London, by Melbourne architects in close consultation with all three covert 'Advisers'. The ANU supported Ph.D. scholars and postdoctoral fellows in Manchester and London from 1965, who transferred with the Professors to Canberra in 1967.

Canberra 1967-1980, and retirement

Canberra was different, too. The remarkable ANU was and still is unique, not only in Australia. Conceived to provide research and postgraduate training to rebuild the nation following World War II, it inherited undergraduate Faculties from the Canberra University College in 1960. Prominent expatriates were recruited to lead the generously funded Research Schools in its Institute of Advanced Studies, and Chemistry was the fifth to be established. 'Project C' emerged from a hockey field as a structurally elegant and technically efficient building, with the internal flexibility needed for a rapidly advancing science and laboratories designed for sophisticated instrumentation. For the organic chemists there was then a mass spectrometer and a 100 MHz ^{1}H NMR spectrometer; by 2004 the School would run six mass spectrometers, and six NMR spectrometers operating from 200 to 800 MHz. The Research School of Chemistry was officially opened by Birch's Cambridge mentor, now Lord Todd of Trumpington, in 1968.

Counter to ANU practice and causing opposition from those who believed "nothing should be done for the first time", the ‘Advisers’ had prescribed a School comprising research groups without the traditional departmental divisions, overseen by a Dean rather than a Director, and sited adjacent to the existing Chemistry Department to promote interaction. Birch was the Dean Elect from 1965, and Foundation Dean from 1967-1970. He served again as Dean from 1973-1976, and retired as Foundation Professor of Organic Chemistry in 1980. The School’s prime purpose was to conduct fundamental research at the highest international level, some aspects of which had potential application to Australian industry and national interests. In so doing it would provide opportunities and training for young Australians both at home and overseas. The School’s research record into the twenty-first century has vindicated the judgement of its founders. The main building of the Research School was named in honour of Arthur Birch at a ceremony, which, despite fading health, he attended with great satisfaction in August 1995.

Birch’s personal research in Canberra developed his Manchester themes further, but with increasing emphasis on the organometallic chemistry of tricarbonyliron complexes with organic ligands. Metal-ammonia reduction provided the cyclohexadiene ligands, the reactivity of which was substantially altered and stereospecifically controlled by the transition metal attached laterally in a reversible fashion. Efficient syntheses of highly functionalised natural products emerged, but the concepts and methods were general and lent themselves to exploitation. With his major biosynthetic hypotheses now confirmed and the results of isotope incorporation studies becoming routine, this area was gradually phased out. Natural product studies were initiated using the new automated counter-current distribution apparatus to resolve complex mixtures, such as the phenolic resins from Australian grass trees which he had observed as a youth, but also gave way to the new developments in organometallic research.

In 1980 Birch reached the then mandatory retirement age of 65. In February 1981 the Research School of Chemistry honoured his achievements and contributions with a major symposium, involving participants from across Australia and overseas. Professor Albert Eschenmoser of the Eidgenössische Technische Hochschule, Zurich, gave the inaugural Birch Lecture, since then an annual event on the School’s calendar. At the Symposium Dinner Birch was presented with the Leighton Memorial Medal of the Royal Australian Chemical Institute (RACI) (its most prestigious medal, awarded "in recognition of eminent services to chemistry in Australia in the broadest sense”) by the Governor-General of the Commonwealth of Australia, His Excellency the Right Honourable Sir Zelman Cowen, and delivered the Leighton Address on “Creative and Accountable Research” (13). Shortly after, he took up the inaugural Newton-Abraham Visiting Professorship at Oxford, returning to the ANU in 1982 as a University Fellow in the Department of Chemistry. In 1987 he was awarded the Tetrahedron Prize for Creativity in Organic Chemistry. In 1994 the RACI made him one of their few Honorary Fellows, and in 1996 the Organic Chemistry Division of the Institute named their premier award in his honour.

The establishment of the Research School at the ANU demanded more of Birch’s time in onerous school organisation and broader university administration than at

Manchester, particularly during the periods of his Deanship. This drawback was partly offset by the absence of undergraduate teaching responsibilities, but far greater compensation came from observing the success of his endeavours. Demands upon his time from outside the university also increased, which as a professional scientist he felt a moral obligation to meet both before and after his retirement. He was appointed Treasurer of the Australian Academy of Science from 1969-1973, Vice-President then President of the Royal Australian Chemical Institute in 1977-1978, and was elected President of the Australian Academy of Science from 1982-1986. During his Presidency of the Academy he was instrumental both in reorganising and in securing much needed headquarters for its administration. The offices now occupy an elegantly refurbished 1927 government hostel which retains its distinctive original exterior and is listed on the Register of Significant Twentieth Century Architecture, adjacent to the "Dome", a Canberra architectural landmark housing the conference hall of the Academy.

As an international scientist of standing, Birch's advice was also extensively sought beyond academia by governments in Australia and overseas. One of his major undertakings was to chair the 1976-1977 Independent Inquiry into the Commonwealth Scientific and Industrial Research Organisation, the large and widespread Australian government research body (12). The inquiry reaffirmed the role of CSIRO as strategic, mission-oriented research in the national context. It proposed radical changes to its longstanding structure, however, including notably the grouping of the many operating units of the organisation, the Divisions, into six Institutes under an Advisory Council and Executive. Most of the recommendations were accepted and implemented by the Government, not entirely to the joy of the scientists involved; subsequent changes built on these recommendations. He was appointed Foundation Chair of the Australian Marine Sciences and Technologies Advisory Committee from 1978-1981. In 1987 he was made a Companion of the Order of Australia (AC) for his contributions to science in Australia.

At the international level, he was an examiner for the Organization for Economic Cooperation and Development (OECD) on Science and Technology Policy in Denmark. For an extended period from 1979-1987 he was Consultant to the UNESCO United Nations Development Programme project on "Strengthening Research and Teaching in Universities" in the People's Republic of China, and made six visits to that country advising on technical and laboratory management and instrument centres. International honours included appointments as Academician of the USSR Academy of Science in 1976 and Foreign Fellow of the Indian National Academy of Science in 1989.

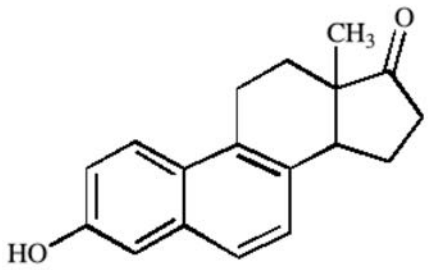
Birch's scientific autobiography, incisively entitled "To See the Obvious", was written over the last ten years of his life for the American Chemical Society series "Profiles, Pathways and Dreams. Autobiographies of Eminent Chemists" (18). With Arthur now seriously ill, the Editor and Publishers responded to an urgent request from Jessie Birch, and it was published just before his 80th birthday in August 1995.

SCIENTIFIC RESEARCH[7]

Birch's scientific research is described in over 400 publications, which range in subject matter from organic synthesis to biochemical processes and organometallic chemistry. In this Memoir we can do no more than attempt to outline the origins, essence and significance of his three major research themes; the Birch reduction, his polyketide theory of biosynthesis, and his studies of the organic chemistry of transition metal complexes.

The Birch Reduction

Solution of the structures of many steroids during the 1930s led immediately to efforts to bring these biologically important compounds into the domain of synthetic organic chemistry, which at that time was heavily biased towards derivatives of benzene and other aromatics readily supplied by distillation of coal. Thus sterols tended to be seen as "hydroaromatic" compounds. It is no coincidence that the first steroid to be synthesised was the naphthalenoid equilenin (**1**) and that the second was oestrone (**2**). Alicyclic chemistry had been stimulated by work on the essential oils, but synthetic methods and control of stereoisomerism were still rudimentary. Methods for reduction were especially backward. Metallic sodium in association with alcohols was one of the more powerful reagents: it could, for example, reduce esters to alcohols and could add two hydrogen atoms to many naphthalenes but it was largely ineffective for reducing solitary benzene rings. For that, hydrogenation over large amounts of platinum black or at high pressures and temperatures over nickel or copper-chromium catalysts was the most general method; but it was stereochemically indiscriminate and it could alter or remove functional groups. Full appreciation of aromatics in steroid synthesis was also delayed by a curious failure to recognise that vinyl ethers are easily hydrolysed by mild acids to carbonyl compounds. Methoxyl groups on aromatic or saturated carbon atoms need vigorous methods for cleavage – the classical reagent is boiling hydriodic acid – and it seemed to be taken for granted that vinyl ethers would be similarly resistant.



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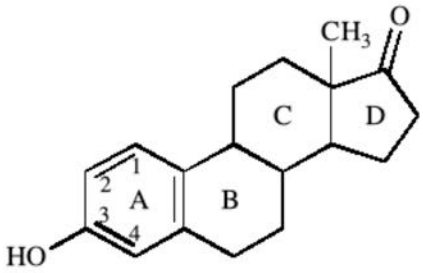
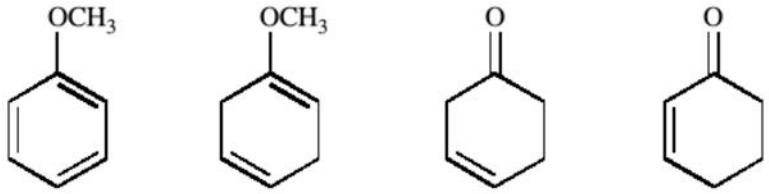


2

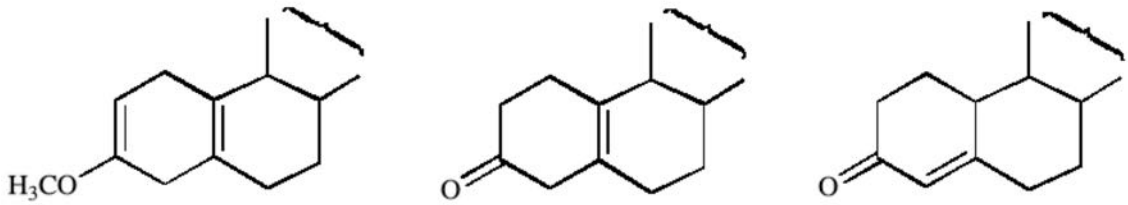
Birch's crucial experiment in 1943, already outlined in the section on his Oxford days, combined two recent discoveries: that solitary aromatic rings could add two hydrogen atoms when treated in liquid ammonia with a combination of sodium metal and an alcohol, and that vinyl ethers were excellent sources of carbonyl compounds. Thus his methoxybenzene (**3**) gave on reduction the 2,5-dihydro derivative (**4**) which

was hydrolysed by mild acid to cyclohex-3-en-1-one (**5**) and thence by acid-catalysed isomerisation to cyclohex-2-en-1-one (**6**) (1). Several important steroid hormones are formally derivatives of cyclohexenone; in addition, cyclohexenones are useful intermediates for further synthesis. In Birch's hands phenolic ethers became packaged cyclohexenones, stable to many manipulations of functional groups elsewhere in the molecule and unpacked by a procedure that left many of these groups untouched. In a series of mostly single-author papers published between 1944 and 1950 Birch laid the foundations of this uniquely useful and, as it turned out, timely method (2). Dialkylaminobenzenes were shown to be reduced in the same manner as alkoxybenzenes (a procedure that has perhaps received less attention than it deserves). Allylic and benzylic alcohols were deoxygenated. The technical difficulty, that many substrates were insoluble in liquid ammonia, was palliated by substituting 2-hydroxyethyl or glyceryl ethers for the usual methyl ethers. Other workers, later, found that lithium was preferable to sodium in some special cases. Birch's original assignment to synthesise analogues of steroid hormones was to succeed beyond measure — but largely in other hands.

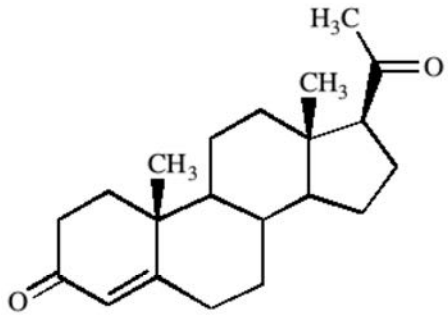


3 **4** **5** **6**

Herchel Smith, his graduate student at Cambridge and his colleague at Manchester, devised along with others some commercially practical methods for synthesising oestrone (**2**) and many analogues, and the last intermediate in these syntheses was almost always a methoxybenzene. When the Birch reduction was applied to these intermediates, hydrogen was added at the 1- and 4-positions (steroid numbering) and the products (**7**) by acid-catalysed hydrolysis and rearrangement gave enones (**8**) and (**9**)**.** The structural element (**9**) occurs, of course, in many natural androgens and progestogens as well as in the adrenal hormones, but these also feature an angular methyl group between rings A and B, as in progesterone (**10**).



7 **8** **9**



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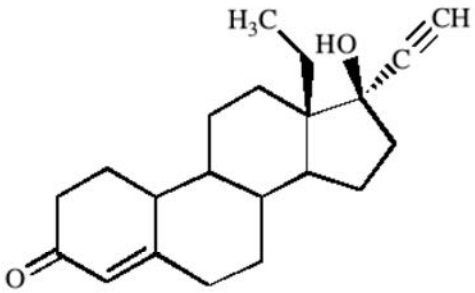
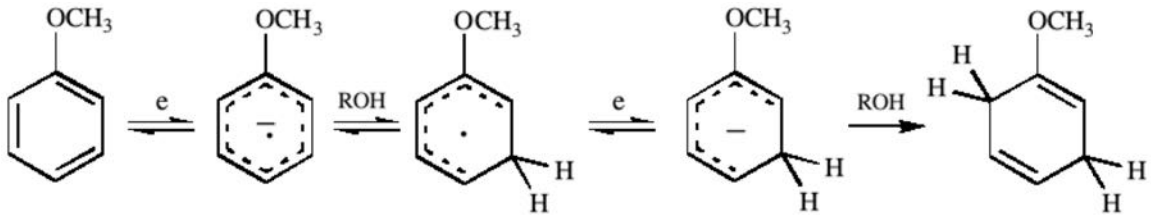


11

The synthetic enones lacked this angular methyl group between rings (A) and (B). It was possible though inefficient to introduce it *via* halocarbene addition to suitably protected intermediates (**8**). But the principle of the contraceptive pill (daily oral intake of a combination of progestogen and oestrogen) had meanwhile been discovered and, unpredictably, many synthetic compounds devoid of this angular methyl group were found to be equal or superior (for this purpose) to the natural hormones. The progestogen norgestrel (**11**) made Herchel Smith a multimillionaire.

Although the Birch reduction is a practical method *par excellence* (10), Birch felt bound to understand its mechanism: why were the protons added where they were and what was the role of the alcohol? His final paper on this subject was a collaboration with Leo Radom who used *ab initio* calculations to substantiate a mechanism already adumbrated by the early experimental work (15). From methoxybenzene (**3**), acceptance of a solvated electron from the sodium-ammonia solution leads, reversibly, to a radical-anion (**12**) that in turn accepts, reversibly, a proton from the alcohol. The resulting neutral radical (**13**) accepts, reversibly, a second electron to form a stabilised anion (**14**). The final addition of a second proton to this anion is virtually irreversible in the usual conditions for Birch reduction and it leads to the terminal product 2,5-dihydro-1-methoxybenzene (**4**). This and similar products were not only sources of cyclohexenones but after complexation with metal carbonyls were the basis for what Birch called lateral control of synthesis (see later).

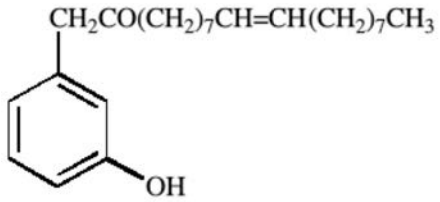


3 **12** **13** **14** **4**

Studies in Relation to Biosynthesis

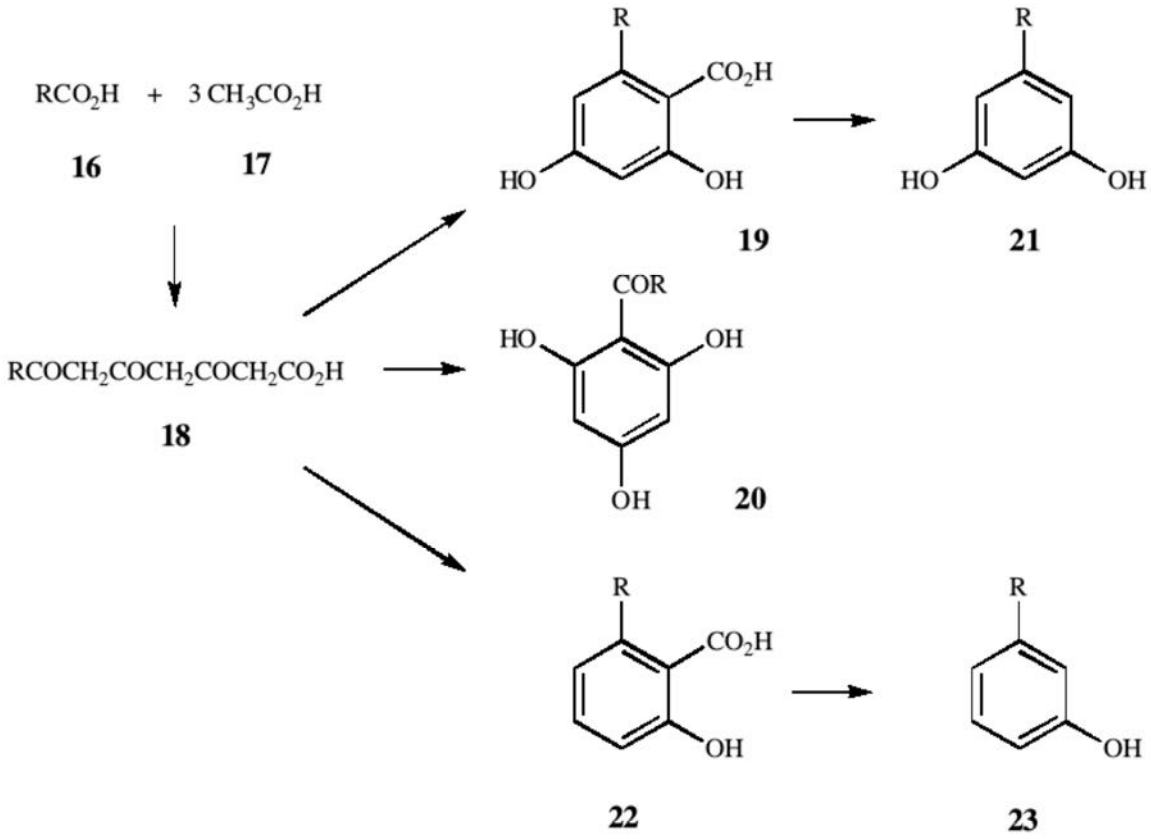
By the early 1950s the fundamental role of amino acids in the biosynthesis of alkaloids and some aromatic compounds had been recognised, as had the role of acetic acid in fatty acid and steroid biosynthesis. In contrast, the origin of the

increasing numbers of phenolic compounds isolated from various plant and microbial sources was not yet understood. It was such a compound from a New Guinean tree which provided Birch with the inspiration for his second major contribution to science, his polyketide theory of aromatic biosynthesis. The original authors had recognised that the carbonyl group in the side chain of campnospermonol (**15**) defined a C_{18} "oleyl radical with … possible generic connection with the fatty oils" (Jones & Smith 1928). Birch realised that if the presumed acetate-derivation of this segment was extended further, and coupled with decarboxylation and loss of oxygen, it could account for the origin of the phenolic ring, and in particular the position of the phenolic hydroxyl *meta* to the side chain.



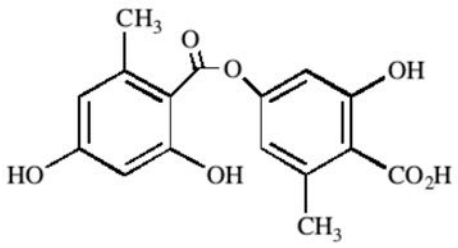
15

From this emerged his "acetate hypothesis", published from Sydney in 1953, whereby "the head-to-tail linkage of acetate units (**17**) could lead to phenolic substances in several ways" (3). Ring closure of polyketonic intermediates of the type (**18**) through aldol condensation or C-acylation could yield orcinol (**19**) or phloroglucinol (**20**) derivatives, respectively (Scheme 1). Superimposition of other biochemically acceptable reactions, such as decarboxylation, reduction, dehydration, oxidation and halogenation, on these basic processes would extend the range of possible products (*e.g.,* **21**-**23**). The chain-initiating acid RCO_2H (**16**) could be acetic or other natural aliphatic acids, or aromatic acids such as hydroxycinnamic acids in the case of plant stilbenes and flavonoids. The carbon skeleton and residual oxygen functionality of the resulting metabolite defined the folded polyketonic intermediate. Birch later termed such metabolites "polyketides", in deference to the early ideas of J. N. Collie in 1907.



Scheme 1

Initial support for the acetate hypothesis came from structural analysis of a range of phenolic metabolites. Lecanoric acid (**24**) is the simplest of the lichen depsides, containing two orsellinic acid (**19**; R = CH_3) units in ester linkage. Partial structure (**25**) summarises the structures of the acid units present in all the depsides then known (4). Particularly convincing was the presence of carboxyl at position 1, oxygen at positions 2 and 4, and an odd-numbered alkyl chain at position 6 of all these units, in full agreement with Birch's hypothesis. In contrast positions 3 and 5 carried occasional oxygen, chlorine and methyl substituents, arising by secondary modifications.



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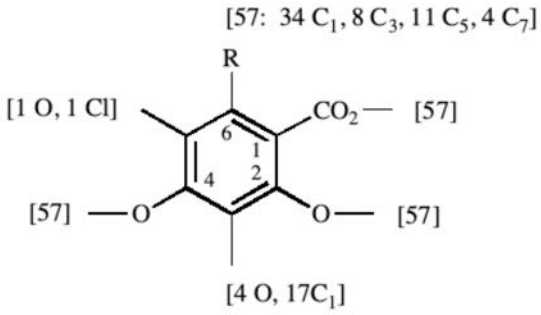
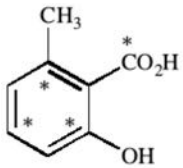


25

Biochemical proof of the hypothesis was provided by examination of the distribution of radioactive carbon (indicated *) in 6-methylsalicylic acid (**26**) produced by growing the fungus *Penicillium griseofulvum* in the presence of [*carboxyl*-^{14}C]-labelled acetic acid (4). Like campnospermonol (**15**), this metabolite has also lost an oxygen of its polyketonic precursor by reduction and dehydration, but in contrast retains the carboxyl group. This was the Sydney forerunner of an extended series of radio-isotope studies of the biosynthetic origins of diverse fungal and bacterial metabolites, carried out in Manchester and using detailed degradative chemistry to locate the radiolabels; the ease of pinpointing heavy isotopes with nuclear magnetic resonance spectrometry was not yet available.



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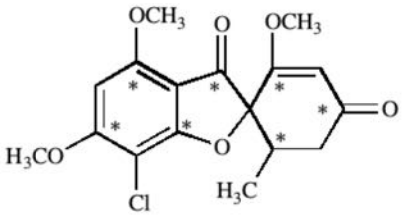

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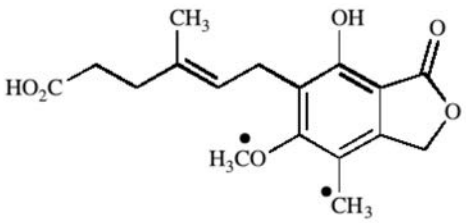
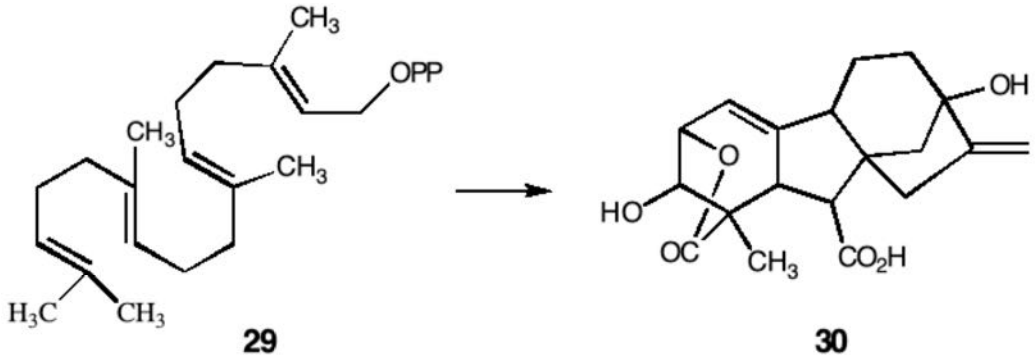


28

The acetate theory was confirmed when griseofulvin (**27**) in *P. griseofulvum* was shown to arise from a chain of seven acetate units (indicated *), modified by O-methylation, halogenation, phenolic oxidative coupling, and reduction stages (5). The occurrence of additional C-methyl substituents, as in the lichen depsides (**25**) mentioned above, was shown to be an extension of the known biological O- and N-methylation by transfer from the S-methyl group of the amino acid methionine; the O- and C-methyl groups (indicated •) on the modified orsellinic acid nucleus of mycophenolic acid (**28**) from *P. brevi-compactum* both arose in this way (6). The C_7-chain of **28** confirmed another general process predicted by Birch, involving C-alkylation with a terpenoid moiety (which here suffered subsequent degradation at its terminus) (7).

The acetate theory with its associated concepts now correlates the structures of many thousands of natural products. Subsequent work by others showed that while the polyketide chain biosynthesis is indeed initiated via acetyl or another acyl coenzyme A, the "acetate units" (**17**) extending the chain are incorporated not directly via acetyl coenzyme A as suggested by Birch but rather via its carboxylation product, malonyl coenzyme A, with concomitant decarboxylation. This detail, although significant biochemically, in no way detracts from Birch's theory.

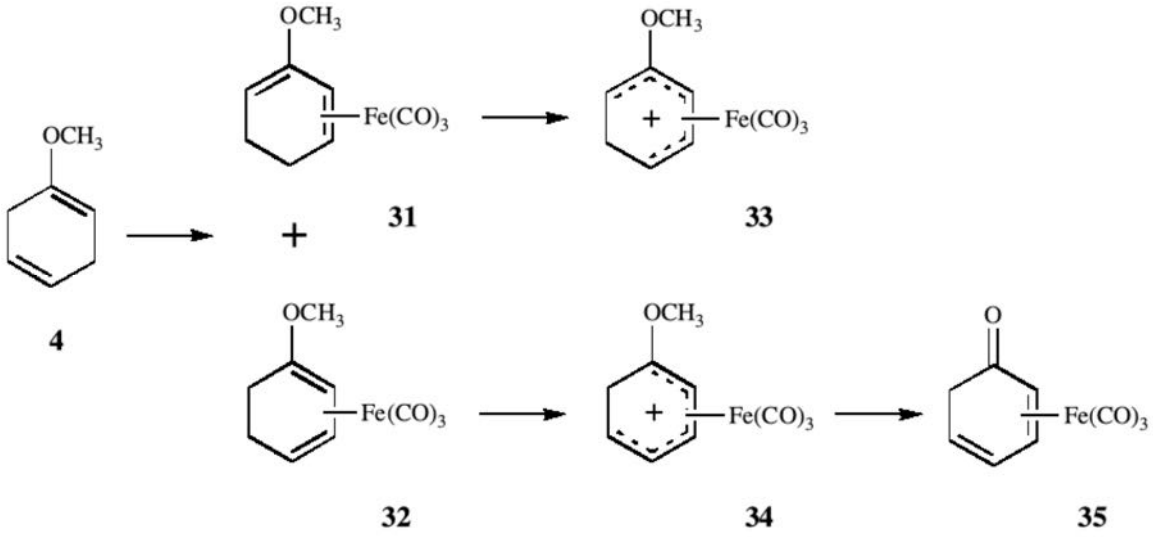
Fungi also provided the vehicle for studying some aspects of terpene biosynthesis, by then known to proceed from acetate through the intermediacy of mevalonic acid to isoprenoid chains which could undergo concerted cyclisation and further modification. The important C_{19} plant hormone gibberellic acid (**30**) from *Gibberella fujikuroi* was proved to be a degraded diterpene, arising from a C_{20}-precursor (**29**) by predictable and stereospecific biochemical processes (8).



29 30

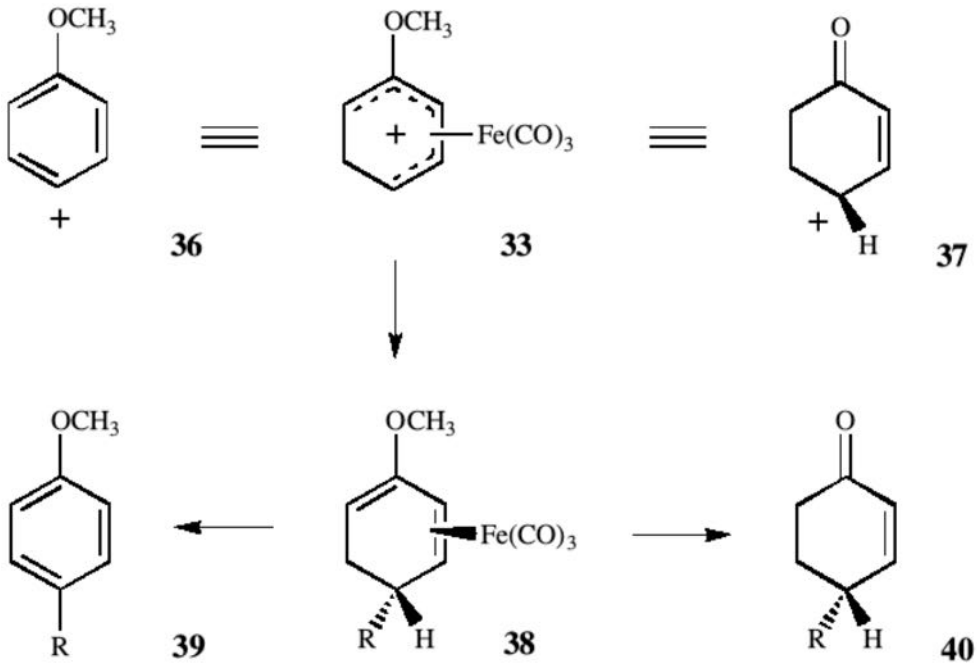
Transition Metal Complexes in Synthesis

Birch's development of the use of iron carbonyl complexes in synthesis arose from his ready access to unconjugated dihydrobenzenes, such as 2,5-dihydro-1-methoxybenzene (**4**), from the reductions discussed earlier. Reaction with iron pentacarbonyl gave the conjugated isomers (**31**) and (**32**) of the iron tricarbonyl complex. An attempt to separate these as crystallisable salts by the removal of hydride with triphenylmethyl tetrafluoroborate gave the stable salt (**33**) from the former complex, but the isomeric 1-methoxy salt (**34**) from the latter complex was unexpectedly hydrolysed to the neutral dienone complex (**35**) (9). This last compound was of interest as a stabilised ketonic tautomer of phenol, but it was the stable salts of the type **33** which proved to be of greater value in synthesis.

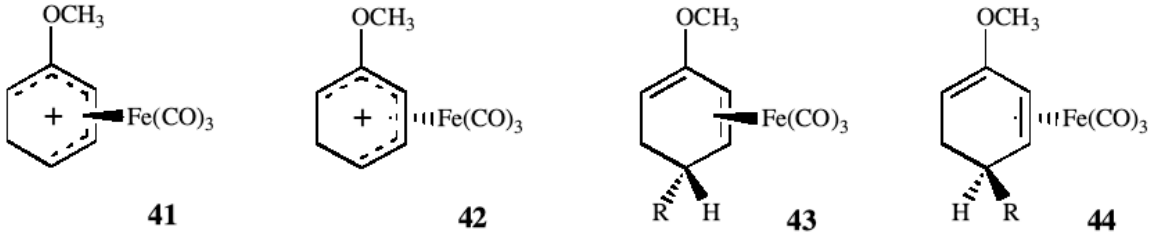


An extensive series of iron tricarbonyl complexes of substituted cyclohexadienes was prepared, and their novel reactivity with a range of reagents studied (11). The presence of the attached but readily removable transition metal resulted in "superimposed lateral control of reactivity, stereochemistry and structure" of the organic ligand (14). For example, the salt (**33**) could behave as the synthetic equivalent either of an aryl cation (**36**) or of a cyclohex-2-enone cation (**37**), depending upon the reaction sequence chosen. Thus reaction with a nucleophile (R) afforded the neutral complex (**38**). Subsequent iron tricarbonyl removal coupled with

dehydrogenation then gave the *p*-substituted anisole (**39**), while coupling with acid hydrolysis gave the 4-substituted cyclohex-2-enone (**40**).

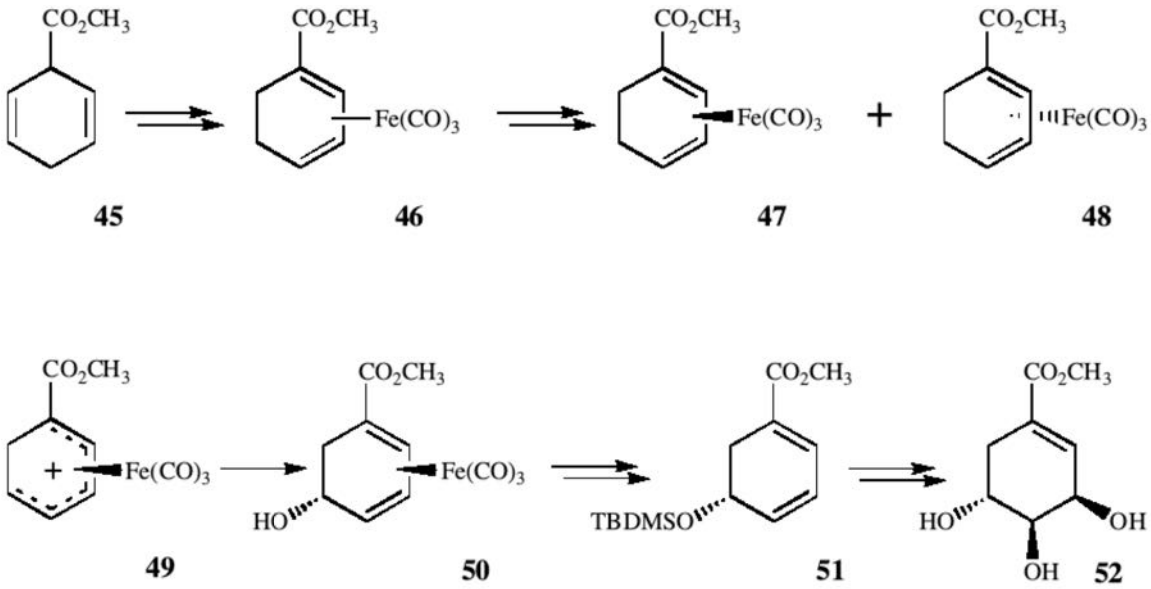


The iron carbonyl group blocks one face of the ring system (**33**), and controls the reaction stereochemistry by forcing the nucleophile to attack specifically from the other face (electrophiles attack from the same face), affording the relative stereochemistry (**38**) shown. This is not always significant, but the salt (**33**) and the neutral complex (**38**) are both chiral, and potentially resolvable into their mirror image pairs, the enantiomers (**41** and **42**) and (**43** and **44**), respectively. The products from such stereochemically pure materials, if they themselves are chiral as is the ketone (**40**), will be stereochemically pure.



The potential of the chemistry is illustrated in one of his last publications, a synthesis of the important biochemical pathway intermediate shikimic acid (Scheme 2) (17). The starting dihydrobenzene in this case is methyl 1,4-dihydrobenzoate (**45**), prepared from benzoic acid by Birch reduction and methylation. Complexation with iron tricarbonyl gave a mixture of dienes isomerised by acid into the single isomer (**46**). This complex could be separated into its mirror image components (**47**) and (**48**) by hydrolysis to the acid, salt formation with (+)- or (-)-phenylethylamine, and re-esterification (16). Hydride removal from the enantiomer (**47**) with trityl fluoroborate now yielded the cation (**49**), which gave the neutral alcohol complex (**50**) on

stereospecific reaction with hydroxide ion. Protection of the hydroxyl group as its *tert*-butyldimethylsilyl ether and removal of the iron by oxidation with trimethylamine N-oxide provided the free diene (**51**). *Cis*-diol formation with osmium tetraoxide and and removal of the protecting silyl group with fluoride ion gave stereochemically pure (-)-methyl shikimate (**52**). Alternative chemistry, again laterally controlled by the iron tricarbonyl group, enabled conversion of the mirror image complex (**48**) to the same product (**52**).



Scheme 2

Birch explored many facets of this chemistry over some twenty years, even beyond his retirement. The powerful methodology has not been utilised to the extent that he expected, however, probably for several reasons. The range of substituted cyclohexadienes readily available from Birch reductions has limitations, and metal complexation frequently yields a mixture of the conjugated diene complexes only one of which is required. Furthermore, the transition metal has to be employed stoichiometrically, and, although iron pentacarbonyl is relatively cheap, applications of organometallic chemistry in organic synthesis were turning increasingly towards catalytic processes.

ARTHUR BIRCH THE PERSON

This memoir has sought to outline Birch's life and career, and his major contributions to chemistry and science at large. His achievements stand on their own merits. His extraordinary talent and his love for his chosen science are obvious, as are his preparedness to accept challenges and his commitment and determination to succeed. Readers will have inferred his ability to lead, glimpsed his dry humour, and seen his concern for the wellbeing of his family. His scientific persona emerges clearly in his scientific autobiography (18). His Oxford mentor Sir Robert Robinson regarded Birch as the student who most resembled him, a compliment accepted by Birch with mixed feelings. Comments by renowned chemists of his era are definitive (18). Sir Derek Barton regarded him as "ten years ahead of his time in three areas: reduction chemistry, biosynthesis, and organometallics". Few chemists achieve this in a single area, let alone in three, and with the pace and maturity of chemistry in the twenty first century it may no longer even be possible. Birch achieved it with relatively few collaborators and limited resources, even by the standards of the time. Carl Djerassi described him as "a maverick, a lone wolf".

For the present memoir, Djerassi commented further: "My enormous regard for Arthur Birch as the quintessence of an original chemical mind can be most succinctly shown by two facts. In the early 1950s I persuaded Syntex - at that time a small pharmaceutical research company in Mexico City - to hire Arthur as one of its chemical consultants. This was the beginning of Arthur's longest professional relation with a pharmaceutical company. Much more significant is my personal conviction that I was the first chemist to publish the word "Birch Reduction" in the literature. But while naming an important chemical reaction after its discoverer is a standard form of homage among chemists, I converted mine into the ultimate compliment: transforming it also into a verb. At Syntex in Mexico City in the mid 1950s, it was standard phraseology 'to birch an aromatic methyl ether.' Que viva Don Arturo Birch!"

Birch's close academic colleague David Craig recalled their interaction over many years. "Although Arthur and I came from the same undergraduate stable in the University of Sydney he was older and we did not meet at that time. We came to know each other well when in 1951 we were appointed to chairs in Sydney, he in Organic Chemistry at 36 and I in Physical Chemistry at 31. The Head of School was Raymond Le Fèvre. I doubt that Le Fèvre felt comfortable with these two brash youngsters. He was probably relieved when in 1955-56 we went back to the UK, Arthur to Manchester and I to London."

"Starting in 1963 and with the strong support of our colleagues and the University, Arthur and I shared the task of establishing the Research School of Chemistry within the ANU. It was a great moment when the School opened its doors in 1967 with Arthur as the first Dean. We were confident that chemistry in Australia had moved forward. The School prospered. We had the same ideas - a firm commitment to a non-departmental structure and a determination that research should have priority over management and administration. In the alternation of the Deanship between

Arthur and me we had an unspoken agreement never to interfere or to look back over what the other had done."

"Arthur stood out, a man of purpose, academic values, good judgment and principles. I was fortunate to have been able to work closely with him over a long period."

His advice to governments was rational and influential. Malcolm Fraser, Prime Minister of Australia from 1975 to 1983 and Minister for Education and Science at the official opening of the ANU Research School of Chemistry in 1968, wrote: "I remember Professor Arthur Birch well. His contribution to the highest scientific research in Australia and overseas won a most distinguished, world-wide reputation. He played a significant, indeed indispensable role in establishing the Research School of Chemistry at the Australian National University. As a university established to foster fundamental research and post-graduate training in Australia, Professor Birch's contribution was outstanding. Its research schools were regarded of real significance to building this country."

"The government then believed in the integrity of academic freedom and the need for fundamental research if science was to advance in Australia and if scientists of the highest international standing were to be attracted to Australia. Professor Birch became a valued advisor to government. He chaired the 1976-77 Independent Inquiry into the Commonwealth Scientific and Industrial Research Organisation and laid the foundations for that organisation's continued relevance and importance. Its task was to accomplish strategic mission-orientated research. His service to Australia continued as Foundation Chair of the Australian Marine Sciences and Technologies Advisory Committee in 1978."

"When asked by government, he felt an obligation to provide service beyond the particular confines of his own discipline. As a consequence he made a most distinguished and broad-ranging contribution to the advancement of science in Australia."

Those who worked for Birch were also fortunate. Research students at their bench soon learnt to recognise the smell of cigar smoke nearby, and to expect the ensuing laconic "Anything new?" Of necessity they also learnt to select from the many ideas he would suggest to them, and to design and carry out the experiments themselves. The sole exceptions were his signature reductions in which he liked to participate, preferably using a conical flask stoppered with cotton wool, frosted at the base by the evaporating liquid ammonia, and swirled by hand as he added pieces of sodium and watched them dissolve in transient blue patches. With longer acquaintance particularly during his Canberra years they saw not only the scientist but also a man of warmth and sympathy, good company and an engaging raconteur, fluent in French which he enjoyed speaking, and with a liking for Mozart.

With regard to his science Birch was certainly self-centred, a trait which may be necessary for outstanding achievement. Was he content with the recognition that he achieved? There were clear reservations as he looked back in an interview at the age of 79 (Wright 1995). In the Australian system he could not obtain significant research

support beyond his retirement; other countries would have welcomed his continuing involvement. His assistance or even his advice had not been sought for ten years – "I haven't been made use of properly in this country". He was critical of both government and industry in Australia. Although he was clearly proud of the Research School of Chemistry and its achievements, his answer when asked if it was worth the sacrifice on his part was "probably no". He was certainly nominated several times for the Nobel Prize, although he did not believe in such major awards.

Behind the frank professional scientist, however, Arthur Birch was a private person. Those who knew Birch before his marriage noticed with pleasure the effect that it had on him. Before, he was a lone wolf who had always had to make his own way; now, he had constant support and love and he could give it too. John and Rita Cornforth were touched when, very late in his life, he told them that they were like a brother and sister to him. He was a welcome visitor to their Sussex home.

In his biography he acknowledges his debt to Jessie, as a nurse for his ailing mother in Oxford and Cambridge, as his wife and mother of their five children, and as the support for his career: "she shared my scientific achievements". She accompanied him twice from England to the other side of the world, where she now lives in the second of their Canberra homes. The first, which she helped to design in the style of a Roman villa around a pool, won the architectural award for a Canberra residence in 1968. An artist in her own right, she has been employed by the National Gallery of Australia, and has made other contributions to arts organisation, the theatre, and family planning. Her enthusiasm for golf was not shared by her husband; even as her caddy he was "useless". Jessie, their children Sue, Michael, Frank, Rosemary and Chris, and their ten "bright and beautiful grandchildren who made him a rich man" were a source of great pride, pleasure, and ultimately strength during the terminal stages of his illness.

Birch's family, and his fighting spirit and humour, sustained him through long illness and successive operations. He died in Canberra on 8 December 1995. He disliked pomp and ceremony, and had said that there should be neither service nor eulogy at his funeral; the occasion was to be more in the spirit of an Irish wake. His wishes were essentially met at his cremation and the subsequent gathering at the Australian Academy of Science on 11 December 1995.

HONOURS AND DISTINCTIONS

Honours and Honorary Degrees

1979 Companion of the Most Distinguished Order of St. Michael and St. George (CMG)
1987 Companion of the Order of Australia (AC)
1962 MSc. (*ad.e.grad.*) University of Manchester
1977 DSc. (*honoris causa*) University of Sydney
1981 MA. (*ad.e.grad.*) Oxon
1982 DSc. (*honoris causa*) Monash University
1982 DSc. (*honoris causa*) University of Manchester

Elected Fellowships and Memberships

1954 Fellow, Australian Academy of Science
1958 Fellow, Royal Society
1960 Fellow, Royal Institute of Chemistry (Chartered Chemist)
1968 Fellow, Royal Australian Chemical Institute
1976 Full Foreign Academician, USSR Academy of Science (first election in Australia)
1978 President, Royal Australian Chemical Institute
1980 Honorary Fellow, Royal Society of Chemistry (Fellow 1936)
1982-85 University Fellow, Australian National University
1982-86 President, Australian Academy of Science
1986 Honorary Fellow, Royal Society of NSW (Fellow 1936)
1989 Foreign Fellow, Indian National Academy of Science
1994 Honorary Fellow, Royal Australian Chemical Institute

Distinctions and Named Lectureships

1937 University Medal in Chemistry, University of Sydney
1945 U.K. Defence Medal (1940-45)
1954 H. G. Smith Memorial Medal, Royal Australian Chemical Institute
1960 Simonsen Lectureship, Chemical Society
1960 University Medal, Universite Libre de Bruxelles
1960 Fritsche (Gunther) Award for Terpene Chemistry, American Chemical Society
1961 Canadian Institute of Chemistry Visiting Professor
1963 E. C. Franklin Award for Outstanding Contribution to Chemistry, Phi Lambda Upsilon, Stanford University
1963 Smith Lectures, University of Oklahoma
1966 Royal Society Delegate, Romania
1966 Wilson Baker Lecturer, Bristol University
1972 Flintoff Medal, Chemical Society
1972 Purkyne Award for Contributions to Biochemistry, Czechoslovak Medical Society
1972 Matthew Flinders Medal and Lecture, Australian Academy of Science
1972 Davy Medal, Royal Society (first award in Australia)
1974 Liversidge Lecturer, Royal Society of New South Wales
1976 Ritchie Lecture, University of Sydney

1980 A. E. Leighton Memorial Medal, Royal Australian Chemical Institute
1980 Masson Memorial Lecturer, University of Melbourne
1980-81 Newton-Abraham Professor, University of Oxford
1981 Robert Robinson Lectureship, Royal Society of Chemistry
1981 Richard Martin Lecture, Universite Libre de Bruxelles
1982 Natural Products Award, Royal Society of Chemistry
1985 Presenté à 1'Académie des Sciences de 1'Institut de France
1986 Plaque, Jurusan Kimia, Institut Teknologi Bandung
1987 Tetrahedron Prize for Creativity in Organic Chemistry
1990 ANZAAS Medal, Australia and New Zealand Association for the Advancement of Science
1991 Medaille Homage, Centre National de la Recherche Scientifique, Produits Naturelles
1992 Dedicated Issue, *Australian Journal of Chemistry*
1995 Main building of Research School of Chemistry, Australian National University, named the Arthur Birch Building

ACKNOWLEDGEMENTS

Details of Arthur Birch's early life and some factual information on his subsequent career are drawn from his scientific autobiography "To See the Obvious", published by the American Chemical Society in 1995. We are grateful to the Birch family, including Jessie, Sue, Michael, Frank, Rosemary, and particularly Chris, for helpful comments and for providing a *curriculum vitae* and publication list. His colleagues Professors Carl Djerassi and David Craig, and former Australian Prime Minister Malcolm Fraser, kindly responded to invitations for personal recollections. We ourselves accept responsibility for other narrative and scientific aspects of this Memoir.

The frontispiece photograph was taken to mark Birch's Presidency of the Australian Academy of Science from 1982-1986, and is reproduced by courtesy of the Academy.

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