

CURRICULUM VITAE

Name: GREEN, Malcolm Leslie Hodder

Address: St Catherine's College, Oxford or
Inorganic Chemistry Laboratory
South Parks Road
OXFORD, OX1 3QR

Date of Birth: 16/4/36, Eastleigh, Hampshire

Nationality: British

Marital Status: Married. Three children

Degrees: B.Sc.(Hons), London; D.I.C., M.A.(Cantab), M.A.(Oxon),
C.Chem., F.R.S.C., Ph.D., F.R.S.

ACADEMIC CAREER

1953-56 Acton Technical College, University of London, B.Sc Hons.
Chemistry

1956-59 Imperial College of Science and Technology, London; D.I.C.
Ph.D. in chemistry. Supervisor Professor Sir G. Wilkinson

1959-60 Post-doctoral Research Associates Fellow. Imperial College
of Science and Technology

1960-63 Assistant Lecturer in Inorganic Chemistry at Cambridge University

1961 Fellow of Corpus Christi College, Cambridge

1963 Sepcentenary Fellow of Inorganic Chemistry, Balliol College,
Oxford and Departmental Demonstrator, University of Oxford

1965 University Lecturer, University of Oxford

1971 Visiting Professor, University of Western Ontario (Spring Term)

1972 Visiting Professor, Ecole de Chimie and Institute des
Substances Naturelles, Paris (six months)

1973 A.P. Sloan Visiting Professor, Harvard University, (Spring
Semester)

1979-84 Appointed to the British Gas Royal Society Senior Research
Fellowship

1981 Sherman Fairchild Visiting Scholar at the California Institute

- of Technology(4 months)
- 1984 Re-appointed British Gas Royal Society Senior Research Fellow (1984-6)
- 1987 Vice-master, Balliol College, Oxford (T.T.)
- 1989 Appointed Professor of Inorganic Chemistry and Head of Department, Oxford University
Fellow of St Catherine's College, Oxford
- 2004- present Emeritus **Research Professor** in the Inorganic Chemistry Laboratory, Oxford University
Emeritus Fellow of Balliol College and St Catherine's College
- Publications** Two text books, 646 refereed papers and 8 patents.

Honours

- 1974 Corday-Morgan Medal and Prize in Inorganic Chemistry (Royal Society of Chemistry)
- 1977 Pacific West Coast Lecturer in Inorganic Chemistry
- 1978 Awarded the Chemistry Society Medal in Transition Metal Chemistry
- 1982 Royal Society of Chemistry Tilden Lectureship and Prize;
A.R. Gordon Lecturer, Toronto University
- 1983 Karl Ziegler Gastprofessor (Max Plank Institute, Mulheim)
J.C. Bailar Lecturer and Medal (Illinois University)
Hutchinson Lectureship (University of Rochester)
- 1984 American Chemical Society Annual Award for Inorganic Chemistry
The University Lecturer in Chemistry, University of Western Ontario
- 1985 Elected Fellow of The Royal Society
Debye Lecturer, Cornell University
Visiting-Professor, Wuhan University, P.R.C.
- 1986 Julius Stieglitz Lecturer, University of Chicago
Awarded Royal Society of Chemistry Medal in Organometallic Chemistry
- 1987 Frontiers of Science Lecturer, Texas A & M University
- 1989 Sir Edward Frankland Prize Lecturer
- 1991 The Glenn T. Seaborg Lecturer in Inorganic Chemistry, University of California, Berkeley
The South-East Lecturer in Inorganic Chemistry, U.S.A.
The Walter Heiber Gastprofessor, University of Munich, Germany
- 1992 The Karl-Ziegler Prize of the Gesellschaft Deutscher Chemiker, Germany
- 1994 Pacific Coast Lecturer, in Organic Chemistry USA, Spring, 1994
- 1995 Rayson Huang Visiting Lecturer, Hong Kong

Humphry Davy Medal of the Royal Society of London.
 1996 Dow Lecturer, Ottawa-Carleton Chemistry Institute, Canada
 1997 American Chemical Society award in Organometallic Chemistry
 Doutor Honoris Causa, University of Lisbon, Portugal
 Frank Dyer Medal, (U of New South Wales)
 1998 The Fred Basolo Medal and Lecture, Northwestern University
 Ernest H. Swift Lectureship, California Institute of Technology
 2000 Sir Geoffrey Wilkinson Medal and Prize, (Royal Society of Chemistry)
 2001 Lewis Lecture, Cambridge UK FMC Lecturer, Princeton
 2002- 2014 Distinguished Visiting Professor, Hong Kong University.
 2002 Distinguished Lecturer in Inorganic Chemistry, University of North Carolina
 34th Canille and Henry Dreyfus Lecturer, Dartmouth College
 2004 Honorary Professor of the University of Wuhan (PRC)
 Bert and Keggie Vallee Visiting Professor, Harvard University, March 2004
 2006 Falk Plaut Lectureship, 2006. Columbia University NY
 Honorary Doctorate Southampton University.
 2007 Prix Franco-Britannique, Société, Française de Chimie.
 2014 Doctor of Science *honoris causa* 14/7/2014, University of Warwick.

Milestones in Original Research Contributions

The early days of research were in the field of synthesis and reactions of organotransition metal compounds and covered the period 1958– 2000. In 1990 research commenced on heterogeneous catalysis and was focused towards hydrocarbon reactions. And in 1993 a completely new area of research into carbon nanotubes started. The highlights of the discoveries made in these areas are listed below in chronological order. Key references are given in *italics*, often together with citation numbers presented as C. xxx (these were taken from the Web of Science on January 24th 2006). Those given in red are particularly noteworthy.

Fundamental reactions of transition metal alkyl and carbene systems

The *first* demonstration of β -hydrogen abstraction from a metal-alkyl system, its reversibility, and its role as a model for the mechanism of metal catalysed olefin isomerisation. ^(12, 15, C 186) The reversible β -elimination reaction is widely available to transition metal alkyls with β -hydrogens.

The *first* demonstration of a reversible α -elimination of a metal-methyl giving a transition metal-methylene-hydride. ^(112 C. 97, 159 C.109) The reversible α -elimination reaction is widely available to transition metal alkyls with α -hydrogens.

The *first* systematic synthesis of metallacyclobutanes and that their decomposition occurred with carbon-carbon bond cleavage, as previously proposed for the olefin metathesis reaction mechanism. ^(125 c.111 129, C.61, 133, C. 87)

The discovery of a general route to the synthesis of hydroxycarbene derivatives of transition metals: the second paper on transition metals carbene systems. ^(62 C. 107)

Pioneering studies of the activation of carbon-hydrogen G-H bonds in aromatic and aliphatic hydrocarbons by transition metal compounds

A.E Shilov first showed that platinum metal systems could catalyse the H/D exchange between deuterium and alkanes and made kinetic studies, However no proposed alkyl-hydride compounds were isolated. The *first* demonstrations for the isolation of stable alkyl- and aryl-hydrides was made by Green, He showed the insertions of a transition metal centers into C-H bonds of both aromatic and saturated C-H *aliphatic* bonds. Both photochemical and thermal activation processes were used. ^{(88 C. 78, 162 C.77, 259 C. 125).}

The synthesis of the *first* zerovalent compounds of the early, refractory transition metal *via* the development of the electron-gun metal vapour synthesis experiment

Metal vapour synthesis was first shown by Peter Timms. The *first* demonstration of the electron gun furnace method for metal vapour synthesis, and its use for the synthesis of the *first* examples of zerovalent bis-eta-benzene compounds of titanium, zirconium, hafnium, niobium and tantalum. The synthesis of bis-benzenetungsten on a large scale (5-10 g) and many other metal atom reactions. ^(96 C. 67, 117, 62, 186 C. 116, 255, 56, 171 C.60, 234, CC.69)
Commercialization of equipment for Metal Vapour Synthesis by G.V. Planer Ltd.

Mechanisms

The *formulation of general rules* for the stereospecificity of nucleophilic addition to organometallic cations (with D.M.P. Mingos and S.G. Davies) ^(148 C. 298)

The formulation of a stimulating and accepted mechanism for Ziegler-Natta catalysed polymerisation of olefins. ^(156 C. 239)

The development of the field of organometallic solid state chemistry

There are several areas which essentially established this new field of research activity ^(303, 305)

The synthesis of the *first* organometallic compound with a large second order non-linear optical behaviour. ^(286 C. 266)

The studies on synthesis and properties of organometallic intercalation compounds ^(121, 143, 152, C.50, 160, 282, 2385, 290, 325, 351, 389, 398)

Studies on redox-active organometallic “soft salts” ^(287, 350)

There are now many active groups in this area. There were 53 recent articles cited under WoS search Organometallic Materials, the most highly cited of which was a review of organometallic non-linear optical materials (> 230 citations).

Pioneering studies on transition metal-hydrogen compounds

The *first* hydrides of tantalum and related tungsten and molybdenum compounds (with Wilkinson). ^(9 C. 226)

The synthesis of the *first* stable nickel-hydride compounds – such systems had long been proposed following the discovery of nickel catalysed hydrogenation reactions by Paul Sabatier in 1913. ⁽⁴³⁾ This work was one of the earliest demonstrations of the use of a bulky tertiary phosphine ligands to achieve increased thermal stability, now a widely exploited strategy.

The development of M-H-C agostic bonds

There were several crystal structures published in which a C-H system very close to a metal atom were reported. However, it was not possible to tell whether this short distance was due to steric effects of the ligand or the formation of covalent bonding to the metal centre. It was the discovery by Green of the agostic-ethyl and -methyl titanium compounds which *unambiguously* demonstrated the existence of the agostic M-H-C bond. ^(194, C.110, 216 C. 92, 251 C. 115)

There is now appreciation of the widespread role of agostic bonds as intermediates in many key metal-hydrocarbon reactions. ^(218 C. 68, 222 C. 1064, 302 C. 653)

A 2014 search for the word agostic using Web of Science gave 1,549 articles published by others using this term since the concept “agostic bond” was proposed in 1983. The word “agostic” has been included in the recent edition of the Oxford English Dictionary. ^(222 C. 1064, 302 C. 653)

More Recent Research Programs

New Heterogeneous Catalysts for the Petrochemical and Green Energy Industries

The *first* catalyst for the *selective* Partial Oxidation of Methane to synthesis gas was discovered in Oxford in 1990. ^(324 C.341, 326 C. 160, 353 C.266) This work attracted worldwide attention in industry. References to patents are listed in the Publications section below. A survey of the Web of Science showed that there have been 4628 articles under the search term “partial oxidation of methane” since the original report and that these publications came from >30 different countries.

The Oxford work also includes the discovery of the excellence of *transition metal carbides as catalysts* for hydrocarbon reforming reactions and Fischer-Tropsch Catalysts ^(472, 503, 511 C. 68, 520, 559, 563, 577, 587, 589, 632)

New carbide catalysts for hydrodesulphurisation have been discovered and patented. A superior catalyst for the oxidative removal of benzothiophenes from diesel has been identified and is being patented jointly with the company Saudi Aramco. Previously the Oxford Wolfson Catalysis Laboratory was set up in Oxford and has been supported for over 18 years by industrial collaborations. These were with the Gas Research Institute, then CANMET Energy Technology Centre - Ottawa (CETC-Ottawa), the Wolfson Foundation and most recently with Saudi Aramco.

An exceptionally active, stable, and selective cobalt carbide catalyst for the conversion of synthesis gas to hydrocarbons (Fischer-Tropsch catalysis) was discovered in Oxford and patented. A spin-off company, originally called Oxford Catalysts Ltd, but has now changed to Velocys (<http://www.velocys>) has been established to exploit the Fischer-Tropsch catalyst which produces gasoline and diesel from methane with greatly reduced sulphur content, as required by new legislation. In 2012 British Airways announced they will invest an estimate £500M over eight years to develop a plant in London to convert London rubbish into jet fuels. This plant is now under construction and Velocys is providing the equipment for the required conversion of syngas derived from the rubbish into the jet fuel (<http://www.velocys>). Recently the US government gave \$72 million Velocys to build a related plant which will convert wood chips from Minnesota forests into transport fuels,

Pioneering studies on the chemistry of carbon nanotubes

This is the most recent new area of research.

It began with the discovery in Oxford of methods to open the ends of multi- and single-walled carbon nanotubes and then their subsequent filling with many materials ^(Patent 415, 423 C. 461, 440 C. 71, 490 C.55, 496 C. 55, 523 C. 93, 587 C.79, 540 C. 114)

Green has shown that nano-crystals inside single wall carbon nanotubes (the worlds smallest crystals) have quite different properties from those of the bulk form of the filling material. The exceptional number of citations gathered in a short period shows the interest in this work.

Most recently the use of wall-functionalized single wall carbon nanotubes filled with a radio isotope of iodine has been shown to locate selectively in the lungs of a mouse. (with Benjamin Davis). This paper is *highly cited*.⁷¹⁸

The development of the Covalent Bond Classification (CBC) method.

The conception and proposal of a revolutionary approach to *the classification of all covalent compounds of the elements*.^(444 C. 164) The ideas behind this work have a slowly but steadily received increasing acceptance and they are now taught to university students in many USA, UK and other countries. For example, lectures are now given to students at MIT, Caltech, Yale, Cornell, Boston *inter alia* and in 10 of the top UK chemistry departments. The CBC method is now used and cited in well-known text books. A recent CBC based classification of two-electron three-centre bonds has attracted attention (with G Parkin and J.C. Green).⁷²⁹ They showed that there are **four** different 3c-2e bonds two of which were not previously recognized. An article to assist the teaching of the CBC method has recently appeared.⁷³¹ A website has been established to assist further expansion (<http://www.covalentbondclass.or>).

All the above work is described in the 732 refereed papers given in the List of Publications and List of 14 Patents. The total number of citations (May, 2014) is >30.000 and the h-factor is 83.

OTHER ACADEMIC ACTIVITIES

Service on National Committees

Review of Synchrotron Facilities, SERC, 1992
Governing Body of the Plant Sciences Institute, AFRC, 1989-1992
Royal Society Committee C3, 1990-1994
Royal Society Committee, Exchange Scholarships (Japan, Far East) 1989-1992
RAE Chemistry Review Panel, 2002
The ERC Advanced Grant committee (Brussels) 2011, 2014.

Conferences organised

Co-organiser (with H. Felkin) of two Table-Ronde Conferences "Transition Metals in Organic Chemistry" and "Activation of Carbon-hydrogen Bonds", Paris, ca. 1973 and 1982, sponsored by Roussel-Uclaf

"Applications of Transition Metals to Organic Synthesis", (with H. Felkin), San Raphael, France 1976, sponsored by CNRS

NATO workshop, "Activation of Carbon-hydrogen Bonds", (with H. Felkin, B. Meunier), Chateau Bonas, France 1985

"Metal Clusters in Chemistry" Royal Society Discussion Meeting (with J. Lewis), London, 1983

"Applications of Transition Metals in Organic Synthesis", Royal Society Discussion Meeting, (with S.G. Davies), London, 1988

" 21st Century Inorganic Materials", Oxford, 1989, funded by the S.E.R.C.

1st European Chemistry Congress 27-31 August 2006, Budapest, session organizer

Invited Lecturers at Universities and Conferences

Early days

Plenary Lecturer: At the Vth (Moscow), VIIth (Japan) and XIth (USA, 1983), International Conferences on Organometallic Chemistry; the 1st, 2nd, 3rd International Conferences on Molybdenum Chemistry; the International Conference on Stereochemistry (Burgenstock), 1974; the A.C.S. Annual Meetings (Chicago) 1974, Miami (1980), Seattle (1982) and St. Louis (1984); I.U.P.A.C. meetings (Toulouse) 1980, Vancouver (1981); the Third I.S.O.M. (Lyon) 1979; 3rd Symposium on Organometallic Chemistry directed towards Organic Synthesis (OMCOS), Kyoto, 1985; NATO Conference on Application of Transition Metals in Organic Synthesis (organising committee), Toulon, 1986. Organiser of Royal Society Meeting on "Applications of Transition Metals in Organic Synthesis: Present and Future", 1988, Table Ronde (Rhone-Poulenc) Paris 1988. 1989/90 DuPont Lecturer, Indiana University. 1990 Ida Beam Lecturer, Iowa University. And many since then.

Invited speaker: Gordon Conferences, New Hampshire, 1962, 1972, 1981, 1982, 1984, 1985, recently 2003, 2005, 2006, , Symposium, Lausanne, 1980; Symposium (Hamlyn) 1979; Andrew Marvell Symposium, Arizona (1981); Rousell Uclaf Table Rond (Paris); organiser and speaker, "The Application of Transition Metal Compounds in Organic Synthesis", 1971 and "The Activation of Carbon-Hydrogen Bonds by Transition Metals", 1982. The Royal Society Discussion on "Metal Clusters" 1982 (organising secretary). Royal Society of Chemistry Symposia and Meetings: London, 1979, 1981, 1982; Edinburgh, 1982. French Chemical Society, Paris, 1986; organising committee of NATO conference on "Activation of C-H and C-C bonds", Bonas, France, July, 1987; many Dalton Meetings and many U.S.A., European and most U.K. Universities.

Invited Conferences and Lectures, March 1990 – July 1994

Topic	Meeting	Date
New Directions in Organometallic Chemistry	RSC Reading	Mar 1990
Ansa-metallocenes for olefin polymerisation	ACS Boston	April 1990
Methane conversion chemistry	GRI Philadelphia	May 1990
Organometallic Chemistry	Gordon C	June 1990
Selective Oxidation of Methane to Syngas.	RSC Birmingham	Sept 1990
η -Cycloheptatrienyl-Transition Metal Chemistry	RSC Strathclyde	Oct 1990
New Ventures in Organometallic Chemistry	Seaborg LBerkeley	April 1991
Organometallic Chemistry	ACS Atlanta	April 1991
Southeast Inorganic Lecture Tour (April-May)	Five schools	1991
Partial Oxidation of Methane to Synthesis Gas.	3rd Euro Wkshop	May 1991

Some Chemistry of the Binuclear Di-Tungsten Compounds $[W(\eta-C_5R_5)Cl_2]_2$.	IX FECHEM Heidelberg	July 1991
Aspects of the Role of Transition Metals in Catalysis.	EUCHEM, France	Sept 1991
Metal-hydrogen-carbon bonds	Boomer L, Alberta	Oct 1991
New Directions in Organotransition Metal Chemistry	Munich	Dec 1991
Chairman	Gordon Conf	July 1992
Tour in Spain, Seville, Madrid, Cadiz. Various topics		Sept 1992
Methane Conversion Chemistry	GRI Chicago	Oct 1992
Various	Caltech, Indianapolis	Mar 1993
Organometallic Intercalation Compounds	RSC Spring Mtg	April 1993
Transition Metal-Hydrogen-Carbon (agostic) Bonds	Intnat Sym, Oviedo	July 1993
Organometallic Chemistry of Fullerenes	IIT, Delhi	Dec 1993
Inaugural Lecture, Chemical Society, University Col	Dublin.	1994
Plenary Lecturer, 30th ICC	Kyotom Japan	July 1994
Invited Lecture, Royal Society of Chemistry, Binuclear Catalysts for Ziegler-Natta Polymerisation	London UK	1994
Invited Lecture, Sonderforschungsbereich International Symposium, "Stereoselective Reactions of Metal-Activated Molecules	Wurzburg,	Sept 1994,
Plenary Lecturer, XVIth International Conference on Organometallic Chemistry	Sussex, UK	July 1994

Since 1994 Professor Green has no longer kept full records of all his outside talk invitations. These have averaged about 4-5 per annum.

For example, most recently Professor Green gave invited lectures at the following Institutions:

Massachusetts Institute of Technology, USA, Spring 2004

Hong Kong University. Two lectures. September 2004

The City University of Hong Kong, September 2005

The Chinese University of Hong Kong, September 2005

Wuhan University, PRC, September 2005

Plenary Lecture EMAG -NANO 2005 Leeds University, UK. 1st September, 200

Editorial boards:

Organometallic Chemistry, Nouveau Journal de Chimie, Reviews in Inorganic Chemistry, Journal of Molecular Catalysis, Polyhedron, Journal of Organometallic Chemistry.

Consultancy Work:

Climax Molybdenum Company, Genetics International, Medisense, and from time to time to British Petroleum Company, Imperial Chemical Industries, E.I. DuPont and Nemours Company, Allied Chemicals and G.V. Planer Co Ltd and in 2005 - present Oxford Catalysts Co. Ltd. Velocys USA.

Past co-workers who have taken academic positions (61)

Professor Green has supervised 136 (Ph.D) graduate students and 38 of his ex-graduate students and 23 of the post doctoral assistants who spent two years in Oxford now hold

tenured academic posts, involving 21 different countries. * indicates a MLHG graduate student.

- * Prof J.T. Moelwyn-Hughes (Witswatersran)
- * Prof J.K.P. Ariyaratne, Kelania, Sri Lanka
- * Prof. W.E. Lindsell, Heriot-Watt.
Prof T. Saito, Tokyo. Japan
Prof R.L. Crabtree, Yale (1 year)
Dr V.M. Akhmedov, Azerbaijan
- * Prof N.J. Cooper, Chicago. US A
- * Dr M. Ishaq, King Abdulaziz, Jeddah SA
Prof J.P. Sauvage, Strasbourg, France
Prof G. Balavoine, Paris, France
- * Prof A.R. Dias, IST, Lisbon. Portugal SA.
- * Orif. C. Romao, IST, Lisbon. Portugal
- * Dr W.E. Douglas, CNRS, Montpellier. Fr.
- * Prof C.R. Lucas, St John's Mem; Canada.
- * Prof F.G.N. Cloke F.R.S, Sussex. UK
- * Dr L. Farrugia, Heriot-Watt, Scotland.
Dr R.P. Clement, Orsay. France.
Prof M.J. Ledoux, Strasbourg, France
Prof J. Sala-Pala, Brest.
- * Dr R. Mahtab, Dacca, Bangladesh
- * Dr S.J. Simpson, Salford. UK
- * Dr P.D. Grebenik, Oxford Brooks, UK
- * Prof M. Canestrani, Caracas, Venezuela.
- * Prof J. Qin, Wuhan, PRC.
- * Dr J.J. Martin-Polo, Mexico.
Prof A. Otero, Aranjuez, Spain.
Prof G. Hogarth, King's Col. Ldn. UK
- * Prof. D. Ng. Chinese Univ. H.K.
Dr A. Danopoulos, Strasbourg France
- * Dr M. Heliwell, Manchester Univ UK
- * Dr P. Luksirikul, Kasetsart Univ.
Thailand
- Prof D. Wigley, Arizona UUSA.
- Prof M. Thompson, Princeton.
- Prof S.R. Marder, Caltech/JPL.
- Prof J. Boncella, Miami. USA
- * Prof D. O'Hare, Oxford.
- * Prof V.C. Gibson, F.R.S.
- * Prof G. Parkin, Columbia. NY
- * Prof L-L. Wong, Oxford.
- * Prof P. Mountford, Oxford.
- * Dr N.M. Walker, Manchester Metr.
- Prof D. Glueck, Dartmouth, USA.
- * Dr J.G. Watkin, Los Alamos. USA
- * Dr A.K. Hughes, Durham. UK
- * Dr R. Douthwaite York UK
- * Prof P. Scott, Warwick. UK
- * Prof J. Bashkin, Washington, USA
- * Dr C-T Chen N. Chung-Hsing Taiwan
Dr J. Sassmanhausen, Graz, UCL, UK
- * Prof M.A. Kelland, Stavanger, Norway
- * Prof A. Sella, University Col. London
- * Prof J.J. Turner, Sussex, UK
Dr X. Morise, CNRS Strasbourg, France
Dr L. Doerrer, Boston Univ, USA
Dr K. Coleman, Durham University, UK
Prof J. Sloan Warwick, UK.
- Dr S. Pascu, Bath. UK.
Prof C. Salzmann Univ. Col. Ldn.
- * Prof G. Saunders, Waikato, NZ
- * Prof P. McGowan, Leeds, UK.
- * Prof G.K-C Lee Kaohsiung
Medical Univ. Taiwan