Chemistry IN NEW ZEALAND

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Comment from the President

We are now well into 2011, the International Year of Chemistry, with details of New Zealand activities available from the joint Royal Society – NZIC website at *http://yearofchemistry.org.nz.* IYC2011 is *a worldwide celebration of the achievements of chemistry and its contributions to the well-being of humankind*, and operates under the unifying theme *Chemistry: our life, our future*. The goals of IYC2011 are to increase the public appreciation of chemistry in meeting world needs, to encourage interest in chemistry among young people, and to generate enthusiasm for the creative future of chemistry.

However, chemistry can have both its good side and its bad side, and a good assessment of both aspects was made by the Journal *Nature*, which dedicated its first 2011 issue to the International Year of Chemistry,[1] and said that *Chemists should celebrate their discipline's past as the foundation of other fields, and face the future with increasing confidence*. However, *Nature* actually began their editorial,[2] entitled *Chemistry's understated majesty*, with a quote from US comedian Adam Sandler: *Chemistry can be a good and a bad thing. Chemistry is good when you make love with it. Chemistry is bad when you make crack with it*. This theme was then followed up by a series of commentaries and articles which looked at both the good and bad aspects of modern chemistry, the *central science*.[2]

The commentaries began with an item entitled *Legal highs: the dark side of medicinal chemistry* by synthetic chemist/pharmacologist David Nichols, who described how his research on psychedelic compounds had been abused, with fatal consequences. People had read his published results on psychoactive compounds in rats, and synthesized the compounds for human use, without any thought about toxicity issues.[3] Other *Nature* articles were less dramatic, focussing not so much on the *dark side* of chemistry, but on some of its shortcomings. For example, an article by Richard Van Noorden,[4] entitled *The Trials of New Carbon* said that despite researchers having spent 25 years exploring the remarkable properties of fullerenes, carbon nanotubes and graphene, commercialization of them has been neither quick nor easy. Similarly, an article by Katharine Sanderson,[5] entitled *It's Not Easy Being Green* looked at how, despite two decades of the green chemistry movement helping industry become much cleaner, the revolution still had a long way to go.

Perhaps the most thought-provoking comments came from George Whitesides and John Deutch,[6] in an article entitled *Let's get practical*, where they said that *Chemistry needs an overhaul if it is to solve big global problems and advance fundamental understanding. Business as usual is not an option*. Specifically, they said that as it grew, *academic chemistry splintered into many specialized subdisciplines*, but while *this structure worked adequately for the relatively simple problems of the last century, it will not work for the more complex problems of the next*. They believe that chemistry has been too slow to exploit new research opportunities, and that *even the best academic chemists have a Prussian-like loyalty to the status quo*. They believe that chemistry needs to be braver in its research choices and in how it organizes them. Old disciplinary structures need to done away with, so chemistry can focus on its strengths.

We can choose to agree or disagree with some or all of the above comments, but regardless of our viewpoint, we can take heart from the fact that, despite all the negativity, the *Nature* editorial concluded with the statement: ***But when chemistry is good, it is very, very good. It deserves its celebration***.

Gordon Rewcastle
President

References

1. See: www.nature.com/chemistry2011
2. Anon., *Nature* **2011**, *469*, 5.
3. Nichols, D. *Nature* **2011**, *469*, 7.
4. Van Noorden, R. *Nature* **2011**, *469*, 14-16.
5. Sanderson, K. *Nature* **2011**, *469*, 18-20.
6. Whitesides, G.; Deutch, J. *Nature* **2011**, *469*, 21-22.

Message to our Readers

We apologise for any delay in the production and distribution of this issue of our journal. You may not realise that the production, printing and mailing of our journal is done in Christchurch and that the aftermath of the earthquake that devastated the city at 12.51 on Tuesday Feb. 22 could well impact on our production team.

Readers will be please to know that none of its Councillors were injured in the quake, which happened while they were at the biannual meeting in the 'Homestead' on the Canterbury University campus. Council had just broken for lunch and were in the second floor cafeteria from which everyone escaped safely; the building was not so lucky and has suffered significant damage. Dr *Gordon* ***Rewcastle*** had received the chain of office from past-president *Mark* ***Waterland*** earlier that morning.

2011 NZIC President Gordon Rewcastle (left) receiving the Chain of Office from Mark Waterland

New Zealand Institute of Chemistry

supporting chemical sciences

April News

The New Zealand International Year of Chemistry was formally launched in the Michael Fowler Centre, Wellington, on Wednesday, February 9th, prior to a fashion display that culminated work by *Jim* ***Johnston*** and his team on impregnating wool fibres with gold nanoparticles. The work was summarized quite beautifully by Dr *Kirsten* ***Lucas*** and then garments made from the nanoparticled wool and designed by Massey University fashion students were shown. The designs were made in a competition of which the winner (most outstanding design) was Greer Osborne. The celebration, hosted by the MacDiarmid Institute AMN-5 conference, was then treated to a public lecture by Professor Sir Richard Friend (Cavendish Professor of Physics, Cambridge) in which the early days of Rutherford led the audience to the modern era *via* superconductivity, ink jet-printed transistors and into current studies on plastic, bendable and almost indestructible displays employing organic light emitting diodes (OLEDs). Later in the week, Professor Sir Anthony Leggett (University of Illinois Urbanna-Champaign) addressed some 1500 school pupils on science, chemistry, physics and why we do it – another magical event that has set IYC off to a great start in this country.

The RSNZ (NZIC) **2011 Marie Curie Lecture Series** was inaugurated by Prof *Margaret* ***Brimble*** (Auckland University) in the Te Papa National Museum lecture theatre on Feb 24 when she spoke on *Exploring Nature's Medicine Chest*. It marked the first of a series of lecture around the country by female chemists/biochemists.

2011 NZIC AWARDS

Nominations for the following 2011 awards are now sought:

Easterfield Award

Maurice Wilkins Prize for Chemical Research,

NZIC Prize for Applied and Industrial Chemistry,

ABA Books Denis Hogan Chemical Education Award.

The closing date with the NZIC Secretariat is 30 June 2011.

Details and method of nomination/application can be found on our website *www. nzic.org.nz*

NZIC MEMBERSHIP MATTERS

FNZIC

Council is pleased to welcome Dr *Michael* ***Hay*** (Auckland Cancer Society Research Centre) to Institute Fellowship.

MNZIC

Mrs *Nathalie* ***Thomas-Zenden*** (Waikato)

Dr *Shaun* ***Hendy*** (Wellington)

STUDENT MEMBERS

Miss *Rosanna* ***Archer*** (Canterbury)

Mr *David* ***Savory*** (Otago)

BRANCH NEWS

AUCKLAND

The first Auckland NZIC Branch seminar for 2011 featured Dr *Donald* ***Wlodkowic*** (BioMEMS Research Group, Auckland University) who spoke on *Lab-on-a-Chip: Advances in Innovative Chip-Based Technologies for Biomedicine*. He outlined his work on the development of innovative micro-fluidic and micro-total analysis systems, with wide reaching applications in medicine, cell biology, clinical diagnostics, and beyond, and the new facilities being established with the Chemistry Department for this work.

Massey University - Albany

A/Prof *Al* ***Nielson*** had a period of sabbatical leave from September to December 2010 at Oxford University working with Philip Mountford on high-valent early transition metal complexes. He attended the Pacifichem conference in Hawaii on the way home and delivered a talk and presented two posters. In January this year he was made a Paul Harris Fellow by Rotary NZ in recognition of his continued work as Academic Director of the Rotary National Science and Technology Forum. Dr *John* ***Harrison*** recently returned from Pacifichem, Stereodynamics 2010 in Santa Cruz, and a short visiting professorship with Prof Dick Zare at Stanford. Dr *Elke* ***Pahl*** was appointed lecturer at Massey University, joining the Institute for Natural Sciences (INS) at Albany. Elke's current research activities are focused on modelling the structure and thermodynamics of nanomaterials, and she contributed a chapter to the recently published *Handbook of Nanophysics*. Elke gave talks on *Towards the Simulation and Melting of Mercury* at the Cluster Meeting (Marlborough Sound) and at the AMN-5 conference in Wellington.

Prof *Peter* ***Schwerdtfeger*** was part of the organizing team for a Pacifichem symposium in Hawaii and gave two invited talks. He then spent one month on a Dumont D'Urville Fellowship in France (Paris, Toulouse, Lyon, Grenoble) collaborating with various research groups on parity violation, Monte Carlo simulations of melting, and on the origin of biomolecular homochirality. He also visited Prof Roald Hoffmann at Cornell University. Peter received the 2010 Humboldt Research Prize valued at 60,000 Euros (for academics whose fundamental discoveries, new theories, or insights have had a significant impact on their own discipline and who are expected to continue producing cutting-edge achievements in the future), and received the Fukui Medal for his achievement in quantum chemistry, in particular for deeper understanding of quantum relativistic effects. Dr *Jonas* ***Wiebke*** joined the Centre of Theoretical Chemistry and Physics (CTCP) as a Fellow working on rare gas simulations from the solid to the liquid state and the gas phase. A further addition to CTCP is Dr *Andreas* ***Hauser*** who is working on methane separation and storage problems. *Susan* ***Biering*** successfully completed her PhD thesis and presented her work at the annual Wagga-Wagga meeting in Australia. A number of visitors came through the CTCP in Albany, details of which can be found in the annual report on the CTCP website. The CTCP chemistry group is also organizing the *5th Asian Pacific Conference of Theoretical and Computational Chemistry* in Rotorua, 9-13 December 2011.

University of Auckland

Prof *Margaret* ***Brimble***, MNZM, was awarded the RSC Natural Products Award for outstanding contributions to the synthesis of biologically active natural products, their derivatives and analogues. She was presented with the medal at a symposium at Trinity College (Dublin) and subsequently delivered the Simonsen Lecture at universities in Ireland and the UK. Margaret was also presented with the RSC Editorial Board Award at the Editors' Symposium in Brussels, in March last year, in recognition of being the Editorial Board member who refereed the largest number of articles for RSC journals in 2009.

Zoe ***Wilson*** was awarded a 2010 Newton International Fellowship by the RSC. The award selects the very best early-stage postdoctoral researchers from all over the world, and offers support for two years at a UK research institution. Zoe will carry out her postdoctoral research at Steve Ley's laboratory, in Cambridge. *Dominea* ***Rathwell*** was awarded the 2010 Hatherton Award by the RSNZ in 2010 for the best paper by a New Zealand PhD student and a 2010 von Humboldt Postdoctoral Research Fellowship to carry out research in the laboratory of Prof Peter Seeberger at the Max Planck Institute of Colloids and Interfaces in Berlin. *Tsz Ying* ***Yuen*** was awarded a Thieme Chemistry and the IUPAC prize for the best poster presented at the 18th International Conference on Organic Synthesis (ICOS-18) that took place in Bergen, Norway last August. All three of these ladies were students under Margaret Brimble's supervision.

Towards the end of 2010, Chemistry HoD Prof *Jim* ***Metson*** ran a two day industry forum for the aluminium industry in the Middle East, followed by a three week residential postgraduate certificate course in Bahrain. The industry forum drew significant participation from Europe, the US, Australasia and the Middle East, and was well covered in the local press. It also provided international exposure for the University's Light Metals Research Centre. Also in the media was Dr *Cather* ***Simpson***, who was interviewed by Bryan Crump on Radio NZ as part of a panel at the 2010 Running Hot conference last November.

Dr *Duncan* ***McGillivray*** was featured in the first *ChemComm Emerging Investigators* issues (No.1, 2011), dedicated to profiling the very best research from scientists in the early stages of an independent career across the chemical sciences. In his article on *Protein aggregate structure under high pressure*, Duncan showed how insights into protein structure, aggregation and stability could be provided concerning casein protein micelles at high pressures (to 350 MPa) through the use of (ultra-)small angle neutron scattering.

Dr *Viji* ***Sarojini*** successfully gained cross-faculty research funding together with the Faculty of Medical and Health Sciences, and secured an HRC scholarship for *Ben* ***Xu*** to work on medical adhesives. Viji lectured at the 12th International Workshop on Fire Blight in Poland last year and an invited talk *Antimicrobial Peptides targeted to* Erwinia amylovora *for Fire Blight Control* at the COST Action 864 meeting held in Belgium last February.

Three University of Auckland chemists are featuring in the IYC Marie Curie lecture series organized by RSNZ, namely Profs *Margaret* ***Brimble*** (Feb – Wellington), *Penny* ***Brothers*** (May – Nelson) and Dr *Cather* ***Simpson*** (Nov. – Christchurch).

Two other students gained awards at Feb 2011 conferences: *Vedran* ***Jovic*** won the best student oral presentation for his talk *Slow photon photocatalytic enhancement in titania inverse opal photonic crystals* at the 34th Annual Condensed Matter and Materials Meeting (Wagga-Wagga, Australia) whilst food science PhD student *Jovyn* ***Ng*** was awarded the Keith Williamson Memorial Medal at the 25th Conference of the Microscopy Society of NZ for her presentation on *Structural Changes in the Cell Walls of Soft and Crisp Apples*.

Department seminars have included Dr *Trevor* ***Smith*** (Melbourne) on *New Results in Ultrafast and Microspectroscopy* (Nov. 2010), and, in 2011, Prof. *Kevin* ***Smith*** (Boston University) presented on the *Observation of Intrinsic Electron Quantum Well States in Solids*, Dr *Kazuo* ***Takeda*** (Chip Biotechnologies Co. Ltd., Tokyo) spoke on *Developing the Micro-fluidic Flow Cytometer – Fishman-R*, and outlined the milestones that led to the development of the flow cytometer and its application to the analysis of cells, Dr *Christian* ***Hartinger*** spoke on *Targeted* vs. *Targeting Strategies in the Development of Organometallic Anticancer Compounds and Studies on their Modes of Action*, and Dr *Ludovico* ***Cademartiri*** presented a seminar *On the Interaction of Flames with Electric Fields*.

Prof *Steven* ***Ley*** (Trinity College, Cambridge) is to present the Maurice Wilkins Centre for Molecular Biodiscovery lecture in May (date and venue to be announced). He has an impressive research record in the total synthesis of natural products, having completed 120 total syntheses to date. His group also specialises in developing new synthetic methods and application of these strategies to the construction of biologically important molecules. Additionally, the Ley group is affiliated with the Innovative Technology Centre, a new state-of-the-art flow chemistry facility, and part of the Cancer Research (UK) PhD Training Programme in Medicinal Chemistry. Further information is available at *http://cmb1.auckland.ac.nz* or from Prof Brimble (*m.brimble@auckland.ac.nz*).

CANTERBURY

The Branch AGM was held on Nov. 24, 2010. *Paul* ***Kruger*** resigned as Secretary, and was replaced by *Francine* **Smith** and *Jayne* **Gulbransen**. *Bill* ***Swallow*** stood down as Treasurer, to be replaced by co-treasurers *Jan* ***Wikaira*** and *Darren* **Saunders**. *Michael* ***Edmonds*** continues as Branch Chairman and is now Institute 2nd Vice-President.

On Dec. 1, Dr *Sheila* ***Woodgate*** (Auckland University) gave a very interesting presentation at the College of Education concerning the interactive web-based learning tool, *BestChoice* (*www.bestchoice.net.nz*). Recent improvements now allow teachers to extract considerable information regarding how individual students are performing, *e.g*. how many answers had to be given before the correct one was obtained. This information was greeted with great interest from teachers in attendance.

Canterbury University

The Chemistry Department Christmas BBQ Luncheon was held Dec. 3, 2010 at the Staff Club. The food was fantastic (thanks to a new caterer), the weather hot and co-operative, and everyone enjoyed themselves. *Joshua* **Smith** was presented with the Branch NZIC Prize as top-ranking 200-level student in BSc Chemistry during the lunch.

A/Profs *Robert* and *Margaret* ***Maclagan*** have now retired. Robert, in Chemistry, started as a lecturer in 1972, while Margaret was in Communication Disorders. Both have been part-time for the last three years and have now assumed adjunct status. Both are intent on continuing with research projects.

New PhD students, *Ruhamah* ***Yunis***, *Tim* **Huber** and *Siji* ***Rajan*** arrived in mid-November. Ruhamah (from Lahore, Pakistan) is working on *Owen* ***Curnow***'s ionic liquid project, while Tim (born in Bühl, Germany) started his PhD in 2009 under the supervision of Mark Staiger, Shusheng Pang, Owen Curnow, Simon Bickerton and Jörg Müssig. His research focuses on the industrial processing of all-cellulose composites *via* ionic liquid. Siji (from India) is working with Prof *Peter J.* ***Steel***.

Prof *Jim* ***Naismith*** (BIC International Fellow) left the Department in mid-January, having organized a workshop covering how to clone, express and purify proteins in a high throughput environment. His research interests are focused on two broad areas: integral membrane proteins and novel biosynthetic enzymes. *Letizia* ***Amato*** (from Salerno, Italy), a PhD student at the Micro- and Nanotechnology Department of the Technical University of Denmark (DTU) spent time between the ***Downard*** and ***Baronian*** groups doing research on carbon nanotubes.

The following staff have been promoted: *Chris* ***Fitchett*** and *Sally* ***Gaw*** to Senior Lecturer; *Paul* ***Kruger*** and *Richard* **Hartshorn** within the A/Prof scale; *Antony* ***Fairbanks*** to Professor. Dr *Nabyl* ***Merbouh*** is now working in Antony's laboratory on several polysaccharide syntheses. *Rob* ***Stainthorpe*** received the VC's Award for General Staff Development and will attend the 13th Annual ICP-MS Symposium in Canberra in April. *Patrick* ***Dronk*** (from Breda, Netherlands) has been an intern, characterizing different types of ionic fluid to complete his degree. PhD student *Wanting* ***Jiao*** was selected as the NZ representative at the 3rd HOPE meeting in Tokyo last March. The meeting, organized by JSPS, brings together *ca*. 100 international PhD students and a select number of physics and chemistry Nobel Prize winners for a five-day get together.

Congratulations from the Branch go to the following students who received their prizes at the Christmas BBQ: *Sam* ***Drew*** (Haydon Prize for top-ranking 300-level student in BSc Chemistry); *Tammie* ***Cookson*** (Ralph H Earle Jr Seminar Prize for 2nd year PhD review seminar); *Sebastian* ***Reichau*** (Dr Gregory S. C. Hii Prize in Organic Chemistry); *Michael* ***O'Donnell*** (C. E. Fenwick Prize in Chemistry for top ranking 400-level student in Hons/MSc Part1/PGDipSc); *Luke* ***Ratten*** (C. E. Fenwick Prize in Chemistry for best 400-level demonstrator in a 100-level lab); *Kim* ***Williamson*** (Jack Ferguson Prize for best performance in labs by a 300-level student); *Kate* ***Dewey*** (Cuth J. Wilkins Prize for best MSc thesis in the previous 12 months).

MANAWATU

The Branch began the International Year of Chemistry with *Women Sharing a Chemical Moment in Time* on Jan. 17th. Co-ordinated by Prof. *Mary* ***Garson*** (University of Queensland), the event linked chemical societies around the globe via video conferencing and focused on the participation of women in chemistry. The Manawatu and Wellington Branches had the privilege of starting the event by connecting with Adelaide and Melbourne. The various societies were linked chronologically according to time-zone with the final connection being between Japan and Hawaii, approximately 24 hours after the initial link between Palmerston North and Adelaide. The event coincided with the MacDiarmid Institute's *NanoCamp* and the students participated in the linkage with Adelaide. *Janice* ***Moody*** (Massey –IFS)

At the NanoCamp

organised the link and Branch Chairperson, *Ghislaine* ***Cousins*** (NZP) attended with other postgraduate students. It provided an excellent opportunity for the NanoCamp folk to interact with other chemists at various stages of their careers.

Massey University

Congratulations to *Adam* ***Stephenson*** and *Rachael* ***White*** who successfully completed their PhDs and married last November. *Karl* ***Shaffer*** also completed his PhD. *Matthew* ***Price*** was awarded a Massey Doctoral Scholarship to work on metal-organic frameworks. *Janina* ***Fischer*** returned from the Max-Planck Institute for Polymer Research, Mainz, to assist with research on the aggregation of dipyrrin complexes. *Shane* ***Telfer*** spent three weeks in Japan during before Christmas as visiting professor at Tokyo Institute of Technology; he also co-organised a symposium on co-ordination polymers at *Pacifichem 2010*.

Department seminars have included PhD student lectures by *Karl* ***Shaffer*** on the *design of ligands with which to bind beryllium ions* and by *Adam* ***Stephenson*** on *The Supramolecular Helical Arrangement of Porphyrins along DNA*. Prof *Bradley* ***Williams*** (Chemistry, University of Johannesburg) gave a lecture on the chemistry of SmI_2 and $Al(OTf)_3$ focusing on their applications towards carbohydrates.

OTAGO UNIVERSITY

Chemistry Department

The Department is proud to announce the promotions of *Stephen* ***Moratti*** to Research A/Prof, *James* ***Crowley***, *Kimberly* ***Hageman*** and *Guy* ***Jameson*** to Senior Lecturer, *David* ***McMorran*** within the Senior Teaching Fellow range, *Jaydee* ***Cabral*** and *Shailesh* ***Goswami*** to Senior Research Fellow.

Sally ***Brooker*** and her PhD students, *Juan* ***Olguin*** and *Humphrey* ***Feltham***, presented lectures at the MacDiarmid Institute AMN-5 conference in Wellington in February. Juan and Humphrey spent the previous week at IRL collecting magnetic data; Humphrey also presented a Departmental seminar on NZ's first single molecule magnet. Sally's PhD student *Worku* ***Gobeze*** and his wife, Woinshet, became proud parents of their first child, Joshua last September. The wedding of PhD students *Scott* and *Rosannah* ***Cameron*** was a wonderful day of sincere celebration for all. Juan Olguin successfully defended his PhD thesis in February and Worku has recently completed the writing of his. PhD student *Rajni* ***Sanyal*** is planning her Dumont d'Urville-funded trip to visit Rodolphe Clerac and Corine Mathionère (University of Bordeaux) to learn more about (photo)magnetic data collection and processing. In the meantime, PhD student *Matthew* ***Cowan*** has made a very nicely behaved spin crossover (SCO) complex, with thermal hysteresis, which Juan characterized at IRL. Victoria Milway departed at Christmas to rejoin her husband who had moved to a new post in Scotland a month earlier. Michael Juchum (University of Mainz) has completed his five-month research project in Sally's group and has returned home. Reece Millar has joined the team and will carry out his honours project working on magnetically interesting complexes.

The Plant and Food Research Unit is hosting Sinna Martinez Villarruel, a pharmacy Masters student from Copenhagen. She will visit for seven months and will study the infraspecific variation of GABA-active flavonoids in the manuka plant and related species, under the supervision of *John* ***van Klink***. The supramolecular and polymer group (*Stephen* ***Moratti*** and *Lyall* ***Hanton***) has welcomed *Susanne* ***Schneider*** (from Germany) as an MSc student. The group has recently given oral and poster presentations at Zing (Mexico), Pacifichem (Hawaii), AMN-5 (Wellington) and APS (Australia).

David ***Weller***, of *Russell* ***Frew***'s research group was accorded the prize for the best student presentation at the Australasian Society for Phycology and Aquatic Botany (ASPAB) conference last November and was voted onto the executive committee of ASPAB as a student member.

Kimberly ***Hageman*** and her PhD students, *Karen* ***Lavin*** and *Ruma* ***Ghosh***, attended the Society of Environmental Toxicology and Chemistry Conference in Portland, Oregon last November. Karen received the 2nd place prize for student presentations (out of 122 candidates). The Hageman group is hosting *Yu-Ping* ***Chin*** (Ohio State) as a sabbatical visitor for six months, until June. The group welcomes *Cleo* ***Davie-Martin*** as its newest PhD student.

Keith ***Gordon***'s research group attended the AMN-5 Conference in Wellington where Keith delivered an invited lecture entitled *Designing New Electronic Materials for Solar Cell and OLED Applications Using Spectroscopy and Computational Chemistry* in the Advanced Photovoltaics session. *Matthew* ***Reish*** gave a talk on *Determination of the Electronic Properties of a Series of Copolymers Using Raman Spectroscopy and QM Calculation* and *Samuel* ***Lind*** spoke on *Modelling Interfacial Electron Transfer in Dye Sensitized Solar Cells*. In addition, posters were presented by *Anastasia* ***Elliot*** on *A Spectroscopic and Computational Study of Porphyrin Excited State Geometries* and by *Raphael* ***Horvath*** on *The Photophysics of Some Phosphazene-Based Small-Molecule and Polymeric Metal Complexes*.

In February, *Keith* ***Gordon*** and *Justin* ***Hodgkiss*** (VUW) were awarded a travel grant from FRST to set up two workshops on photovoltaic research in Korea, and the AMN-5 was an opportunity to liaise with some of the Korean scientists around these up-coming meetings. In December, Keith attended Pacifichem 2010 to present two invited talks, the first in the Molecular Photonics symposium (*Interplay of metal to ligand & ligand based charge-transfer transitions in rhenium(I) complexes with sulfur-containing polypyridyl ligands*) and the second in the Advances in Non-Linear and Linear Spectroscopy symposium (*Tuning optical and electronic properties using computational chemistry and spectroscopy*). In November, the group attended the 6th Asian Photochemistry Conference in Wellington. *Matthew* ***Reish*** gave a talk on *Spectroscopic and Computational Determination of the Electronics of Donor Acceptor Polymer* and *Keith* ***Gordon*** one on *The* *effect on excited state properties on altering communication between charge transfer and emission centres in rhenium(I) complexes*, in which time-resolved infrared results from *Raphael* ***Horvath***'s visit to Michael George's Nottingham group were presented. In addition, Raphael gave a talk on *Spectroscopy of Polymeric and Small-Molecule Phosphazenes: Photoluminescence and Spin-Crossover* and *Sam* ***Lind*** one on *Modelling Interfacial Electron Transfer in Dye Sensitised Solar Cells*.

Late last year, *Keith* ***Gordon*** became a Partner Investigator on the grant, *Next generation excitonic solar cells using advanced charge generation concepts: Setting the new efficiency benchmark*, funded by the ARC (Australian Research Council). The project, to be led by Attila Mozer (Wollongong), will focus on the development of new strategies to boost polymer-based solar cell efficiencies. Keith is also a Partner Investigator on a second ARC grant, *Porphyrin Arrays – Light harvesting in 3D* that was awarded to his PhD graduate, Tracey Clarke. Another ex-Gordon student, Amar Flood (Indiana University), was the recipient of the prestigious 2011 Cram-Lehn-Pedersen prize from the RSC. This award recognizes Amar's *pioneering work in macrocyclic and supramolecular chemistry and, in particular, for his development of receptors that employ pure CH hydrogen bonding to bind anionic guest species*.

Biochemistry Department

Eleven delegates from five groups in Biochemistry escaped the changeable Dunedin summer for the promise of more temperate beaches at the Lorne Conference on Protein Structure and Function LAST February. Held outside of Melbourne at the Erskine Mantra Resort in Lorne, the 36th annual meeting attracted northern hemisphere experts in membrane channels, molecular chaperones, ubiquitin systems, virus structure, and protein dynamics; every session included a healthy dose of structural biology. *Sigurd* ***Wilbanks*** and members of his lab presented X-ray diffraction, single molecule spectroscopy (Samuel Walsh) and phylogenetic comparisons (Jess Renshaw) of the Hsp70 molecular chaperones, as well as an NMR structure of the Psb27 chaperone of photosystem II (Peter Mabbitt). *Liz* ***Ledgerwood*** and her student Tracy Josephs reported on cell signalling mechanisms by peroxiredoxins and cycotchome *c*. *Craig* ***Marshall*** and members of his lab contributed reports on ice active proteins (Stephen Clarke) and an improved X-ray structure of lactate dehydrogenase (Abishek Kumar). In addition, Frances-Rose Schumacher of *Catherine* ***Day***'s lab presented her study of ubiquitin ligases, while *Daniel* ***Garama*** of *Alan* ***Carne***'s lab reported his characterisation of the carotenoid composition of kina roe.

WAIKATO

The 2011 Waikato Branch Committee officers are:

Chairperson: *Graham* ***Saunders***; Treasurer: *Michael* ***Mucalo***; Secretary: *Megan* ***Grainger***.

Waikato University

Keri Thomas, Christina Strawbridge and Yuan Wang have all initiated their MSc projects with *Michael* ***Mucalo*** funded through the Capability Fund from Technology NZ. Each is doing applied research in association with a company, relating to controlled release, colloid science, or resin chemistry (with NMR characterization), respectively. Steven Gardyne also began his PhD under Michael's supervision (with *Alistair* ***Wilkins***, and *Grant* ***Northcott*** – Plant and Food Ruakura). Steven will be tracing the fate of UV active compounds in the environment using a variety of techniques. Sri Lankan Kethsiri Alwis began his PhD with Michael last year, and is studying corrosion of various metals in selected ionic media using IR spectroelectrochemistry as his primary technique, coupled with mass spectrometry. Michael's current MSc student, Jacob Jaine has recently completed his thesis on colloids formed in various media and expects to further his studies in this area.

Of *Brian* ***Nicholson***'s students, *Kyle* ***Devey*** has completed his MSc (with Hill Laboratories) on soil testing chemistry, and was granted TechNZ funding to continue to PhD. Between degrees, he spent several weeks exploring parts of South America. *Cody* ***Wright*** has submitted his MSc thesis, which explored polyoxostibonates, and has a position with Fonterra at its Te Rapa plant.

Summer students working in the Department over the summer were (with *Bill* ***Henderson***) Neville Coughlan - who worked on organogold chemistry, and Paul Crosby - on applications of some inorganic compounds in forensic science. Under *Merilyn* ***Manley-Harris*** was Lily Liang, who investigated the changes in fatty acid composition of clover root weevils during their life cycle, as part of an ongoing joint project encompassing Jolene Brown's PhD project. The lipid metabolism of parasitized and non-parasitized clover root weevils is being examined. Connie Kueh has been studying the mineralization potential of some naturally derived materials for biomedical applications (with Michael Mucalo) and Blair Munro has been working (with Brian Nicholson), synthesizing and examining the ESI-MS of novel polyoxostibonates derived from aryl stibonic acids. *Joseph* ***Lane*** has supervised three students, all involving computer modelling: Jess King on the atmospheric interactions of a new biofuel, 2,5-dimethylfuran, whilst Jane Spenceley undertook a computational study of reactions of phosphine with common atmospheric radicals. Jordan McMahon has been working on explicitly correlated computational investigation of CO_2 dimers and their interactions, Sophie Sim (with *Graham* ***Saunders***) on the synthesis of polyfluoroaryl substituted imidazolium salts and Adelle Nancekivell (with *Alan* ***Langdon***) on possible uses of leaf litter including a biomass source for bio-fuels, functioning as long term carbon stores.

Michèle ***Prinsep*** and Joseph Lane both attended *Pacifichem 2010* last December. Michèle gave a talk *Detection, structural determination and bioactivity of metabolites from bryozoans and cyanobacteria* in the symposium Recent Advances in Natural Products as Anticancer Agents, whilst Jo gave two talks – *Application of explicitly correlated coupled cluster methods for accurate potential energy and dipole moment sur-*

faces and *Benchmark calculations of weakly bound complexes obtained with explicitly correlated coupled cluster methods* in the symposia Computational Quantum Chemistry: Theory and Interactions with Experiment and Anharmonic Vibrations of Molecules and Clusters: Experiment and Theory, respectively.

WELLINGTON

The Branch had as its first event of 2011 the Women's networking breakfast on 18 January at the Southern Cross Hotel. When finished, Wellington handed over to events in Palmerston North and Australia through Skype calls, and the process continued through the world, finishing in Hawaii (who handed back to Wellington). Some 30 lady members attended our event and, overall, more than 40 countries participated in this celebration of IYC and Madam Curie.

The first formal Branch meeting of the IYC year was at the customary time of the 2nd Wednesday of the month. It happily coincided with the formal launch of IYC in this country and many members attended (see above). The first of the Marie Curies public lectures also took place in Wellington on February 24 when *Margaret* ***Brimble*** spoke in the Te Papa lecture theatre on *Exploring Nature's Medicine Chest*.

Victoria University - SCPS

Recent visitors to the School have included Drs *Robin* ***Fulton*** and *Martyn* ***Coles*** (Sussex University) and *Nicola* ***Brasch*** (Kent State University). Robin shared her thoughts on the *Reactivity of Divalent Complexes of the Heavier Group 14 Elements* in early December. She described her synthesis of a series of low-coordinate divalent germanium-, tin- and lead-alkoxide, -amide and -phosphide complexes utilising a bulky β-diketiminate ligand to stabilise the metal centre. These group 14 alkoxide and amide complexes have shown limited nucleophilicity at the nitrogen or oxygen atoms. However, facile reactivity with carbon dioxide has been observed in both the lead and tin systems. Martyn was an applicant for the School's vacant inorganic chemistry position and he spoke of his work on *Bicyclic Guanidines in Ligand Development for Catalytic Applications*. He reminded us that the naturally occurring guanidines have an established history in coordination chemistry and went on to show us that, within the family, the bicyclic derivatives offer several unique properties through his work on transition-metal and main group complexes containing bicyclic guanidine components. Nicola was the other short-listed applicant for the inorganic position and she gave us a potpourri of her research under the title: *From vanadium to vitamin* B_{12}*: combining beauty and health*.

Wednesday Dec. 8 saw Prof *James* ***Watkins*** (Polymer Science and Engineering, Massachusetts University) visit *Richard* ***Tilley*** and give a seminar on *Additive-Driven Self Assembly of Nanostructured Materials and Devices*. It proved to be a fascinating lecture taking the audience from the construction of block co-polymers through self-assembly and nanoparticle incorporation to the long-term industrial possibilities of the materials. On Feb 1 Dr Christoph Borchers (Proteomics Centre, Victoria University, British Columbia) gave a lecture on *Novel Approaches in Structural and Quantitative Proteomics*. He focussed on the development and application of mass spectrometry-based approaches in absolute quantitative and structural proteomics, which for structural proteomics, combines protein chemistry with mass spectrometry (MS), including H/D exchange, photoaffinity labeling/crosslinking and numerous other MS techniques. His quantitative proteomics are focused on further development and improvement of two mass spectrometry approaches, namely, Multi-Reaction Monitoring (MRM) and immuno-MALDI (iMALDI) – both have great potential for biomarker validation and discovery since these approaches are rapid, highly specific and enable absolute and multiplex protein quantitation.

On Feb 17 Prof *Joachim* ***Thiem*** (Hamburh University) revisited VUW and spoke on *Contemporary Synthesis of Complex Bioactive Glycostructures Employing Chemoenzymatic Routes*. The world renowned work of his group provided a fascinating time for the VUW carbohydrate chemists and the others in the audience. In contrast, Prof *Stephen* ***Kent***, who visited on Feb 23, gave a joint seminar to the chemists and biological scientists entitled: *Through the Looking Glass – a New World of Proteins Enabled by Chemistry* where he described how modern chemical ligation methods enable the practical total synthesis of large protein molecules. He showed how the use of racemic crystallography determined the previously unknown crystal structures of a series of protein molecules of ever increasing size. This was also applied to protein quasi-racemates where the resulting pseudo-symmetric crystals can be used to determine protein X-ray structures.

Towards the end of the month Prof *Stephen G.* ***Withers*** (Centre for High-Throughput Biology (CHiBi), University of British Columbia) spoke on *Design and selection of glycosidase inhibitors towards therapies for Diabetes, Influenza and Gaucher disease* describing how *recognition elements* on cell surfaces can be synthesized and degraded using enzymes known as glycosyl transferases and glycoside hydrolases (glycosidases), respectively. Drs *Rebecca* and *Ludovico* ***Cademartiri*** (Harvard University) gave lectures at the end of February on *Understanding Crystallization* and *On the Interaction of Flames with Electric Fields*, respectively.

Mechanistic Studies of Enantioselective *N*-aryl, *N*-alkyl NHC Ruthenium Metathesis Catalysts in Asymmetric Ring-Opening Cross-Metathesis

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About the Author

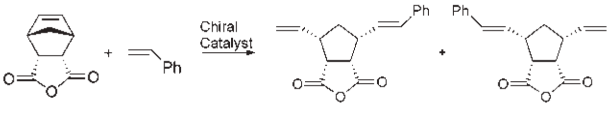
Robert (Bob) H. Grubbs was born in Marshall County Kentucky on February 27, 1942 and gained his high school education at Paducah Tilghman. His BS and MS degrees are from the University of Florida where he worked with the late Prof. Merle Battiste on cyclopropene rearrangements. He transferred to Columbia University for PhD study, which he gained under the direction of Ronald Breslow in 1968. He spent a postdoctoral year with James Collman at Stanford University from where he was appointed to the faculty of Michigan State University. Some nine years later, in 1978, he moved to California Institute of Technology and has remained there since; currently he is the Victor and Elizabeth Atkins Professor of Chemistry.

He was advised that he had been awarded the 2005 Nobel Prize in Chemistry (with Schrock and Chauvin) late on October 5, after having returned to Christchurch (where he was an Erskine Fellow at the University of Canterbury) from giving a lecture at Victoria University in Wellington. His main interests are in catalytic organometallic and synthetic chemistry, where he is especially noted for the olefin metathesis catalysts named after him and for ring-opening metathesis polymerization with cyclic olefins such as norbornene. He also contributed to the development of so-called *living polymerization*.

His numerous awards include an Alfred P. Sloan Fellowship, a Camille and Henry Dreyfus Teacher-Scholar Award, an Alexander von Humboldt Fellowship, the ACS's Benjamin Franklin Medal, Herman F. Mark Polymer Chemistry Award, Herbert C. Brown Award, and Tolman Medal. He was elected to the National Academy of Sciences in 1989 and a Fellowship in the American Academy of Arts and Sciences in 1994. Last year he participated in the US Science and Engineering Festival Lunch and met middle and high school students in an informal conversation with a Nobel Prize winning Scientist over a brown bag lunch.

Introduction

Olefin metathesis is used widely for the construction of carbon-carbon double bonds and has extensive applications in organic and polymer synthesis,[1] as well as materials chemistry.[2] Asymmetric metathesis provides an attractive methodology for synthesizing enantiopure molecules, and significant efforts have been directed toward the development of enantioselective catalysts.[3] *Asymmetric ring-opening cross-metathesis* (AROCM) (Scheme 1) has been employed as the key step in several total syntheses, affording the desired product in excellent enantiomeric excess (ee).[4,5] Applications of AROCM have also been pursued in the synthesis of biologically relevant molecules.[6] Imparting chirality from the catalyst to the substrate is challenging, and has been the focus of catalyst design for this purpose.[7]



Scheme 1. Asymmetric Ring-Opening Metathesis.

Early studies in AROCM focused on molybdenum-based metathesis catalysts, which displayed good selectivity for the reaction of substituted norbornenes with styrene.[8] The enantioselectivities of the molybdenum complexes were substrate dependent, but generally high (>80% ee).[9,10] While AROCM usually yields *E*-olefin products, sterically hindered stereogenic-at-molybdenum catalysts were shown to give excellent *Z*-selectivity, currently unique selectivity to molybdenum catalysts.[11] Ruthenium catalysts were explored owing to their stability to air and moisture, a feature that enables them to be easily handled.[12] Comparison studies showed chiral ruthenium complexes to be comparable, and sometimes superior, to chiral molybdenum catalysts in their enantioselectivity, and the preferred metal was found to be dependent on the particular reaction and substrate.[13]

Chirality has been built into ruthenium complexes primarily in the *N*-heterocyclic carbene (NHC) backbone (see **1**, Fig. 1).[14] Hoveyda and coworkers improved the enantioselectivity of ruthenium catalysts through the synthesis of an *N*-binaphthol NHC with the hydroxyl group chelating to the ruthenium metal (**2**, Fig. 1); however, the catalytic

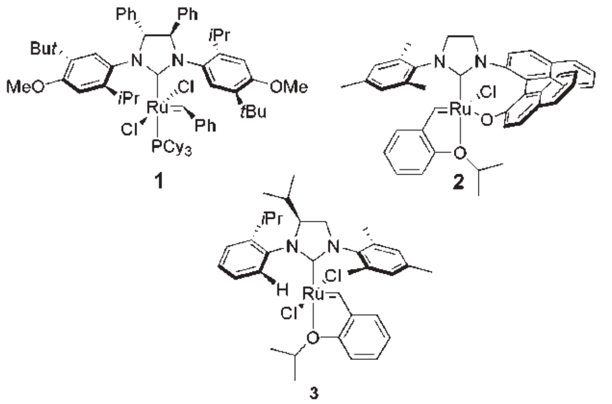
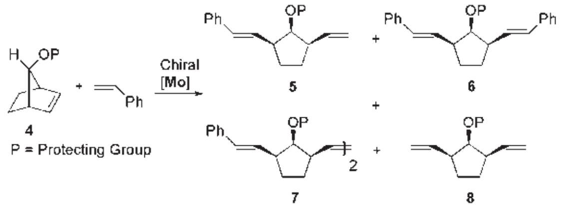


Fig. 1. Ruthenium catalysts reported in AROCM.

activity was decreased.[15,16] The enhanced selectivity of this complex is likely due to the closer proximity of the chiral ligand to the reaction centre, where it can impart a stronger influence on the stereochemistry of the transition state. Recently, Blechert and coworkers reported the synthesis of a chiral mono-substituted NHC backbone that achieved high enantioselectivity while maintaining activity during AROCM of various functionalized norbornenes (**3**, Fig. 1).[17] The NHC backbone substituent, an isopropyl group, was proposed to induce the *N*-aryl ring to twist, creating the desired chiral environment. This is analogous to the mechanism by which the chiral diphenyl NHC backbone catalysts, such as **1**, are believed to impart chirality.[14]



Scheme 2. Side products of AROCM catalyzed by molybdenum complexes.

To the best of our knowledge, there are no detailed investigations of any side products produced during AROCM catalyzed by ruthenium complexes. Schrock and coworkers have disclosed a discussion of possible side products, including the observation of such products, albeit in low yield, for molybdenum catalysts (Scheme 2).[8,9] In addition to product **5**, molybdenum catalysts were noted to give ring-opened products **6** and **8**, as well as homometathesis product **7** in some cases. The authors detail the mechanism leading to the desired **5** and undesired products (**6** and **8**), which has significance for ultimate enantioselectivity, as well as providing information regarding the propagating metal species (alkylidene *vs* methylidene).[9] Product **8** requires ring-opening by a methylidene species. After ring-opening of **4** by a molybdenum methylidene moiety, the styrene cross-partner can react to form either a 2,3- or 2,4-metallacycle to give the major product **5** or product **8**, respectively. However, it is noted that, presuming the catalyst methylidene species has the same facial selectivity as the catalyst alkylidene species, the cross-metathesis reaction with styrene and the methylidene-opened substrate will lead to the opposite enantiomer from that provided by ring-opening with the alkylidene species.[9] This information is valuable for gaining insight into catalyst behaviour, including preference for alkylidene *vs* methylidene propagation and formation of a 2,4- *vs* 2,3-metallacycle. These catalyst attributes are essential to its applications in metathesis reactions.

Herein, we discuss mechanistic studies of chiral *N*-aryl, *N*-alkyl NHC ruthenium catalysts in AROCM. The formation of AROCM side products resulting from metathesis reactions of propagating ruthenium methylidene species was observed. The reaction pathways are discussed, as well as the enantioselectivity of the chiral *N*-aryl, *N*-alkyl NHC complexes studied. Some of the complexes investigated appeared to exhibit unusual preference for methylidene propagation compared to standard second generation ruthenium catalysts. Evidence suggests that these *N*-aryl, *N*-alkyl NHC ruthenium catalysts proceed through both a 2,4-metallacycle and a 2,3-metallacycle during AROCM, accounting for the observed product ratios and distribution. This catalyst behaviour has significant implications for catalyst design and targeted application, as methylidene propagation and metallacycle orientation directly determine product outcome, and can be utilized accordingly.

Results and Discussion

We designed ruthenium catalysts bearing an *N*-aryl, chiral *N*-alkyl NHC, with the goal of bringing ligand chirality in close proximity to the metal centre for increased enantioselectivity during asymmetric metathesis reactions. Since *N*-alkyl, *N*-alkyl NHC ruthenium catalysts are reported to be less active than *N*-aryl, *N*-aryl NHC catalysts,[18] we chose to synthesize *N*-aryl, *N*-alkyl catalysts to ideally maintain good activity while achieving better selectivity.[19] NHC salts **9**-**14** (Fig. 2) were synthesized in an analogous procedure to that outlined by Kotschy and coworkers.[20] The NHC salts were subsequently metallated as previously reported in the literature to give complexes **15**-**20** (Fig. 2).[21]

Complex **15** was initially screened for AROCM, since we anticipated that the large differential in the steric demands of the substituents at the chiral carbon (naphthyl *vs* methyl *vs* H) would provide for a highly enantioselective reaction. Substrate *cis*-5-norbornene-*endo*-2,3-dicarboxylic anhydride (**21**) was reacted with 10 equivalents of styrene to yield product **A** in 69% ee over its enantiomer **B** (Scheme 3) after 2 hours at room temperature (99% conversion). Interestingly, side products **C** and **D** were also observed as 17 and 10% of the product mixture, respectively. Therefore, subsequent experiments were directed toward elucidating the pathway to the formation of these two side products. No polymer or homometathesis product was observed in the reaction mixture, although stilbene was formed from the cross-metathesis of styrene. The products all had *trans* stereochemistry, with no detectable *cis* isomers.

Formation of product **C** could result from the cross-metathesis reaction proceeding *via* a 2,3-metallacycle, and/or by secondary metathesis of products **A** and **B** with styrene. Breakdown of the 2,3-metallacycle to yield product **C** generates a ruthenium methylidene species, whereas reaction *via* a 2,4-metallacycle to afford the major products **A** and **B** gives a ruthenium alkylidene species (Scheme 4). Secondary metathesis of products **A** and **B** with styrene, reacting *via* a 2,3-metallacycle, also generates a ruthenium methylidene species (Scheme 5). Accordingly, formation

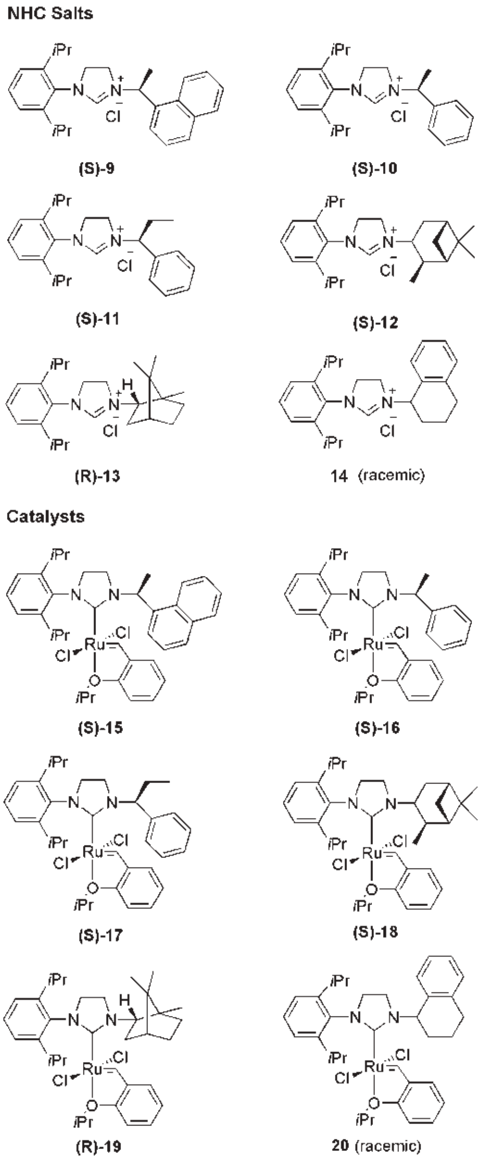
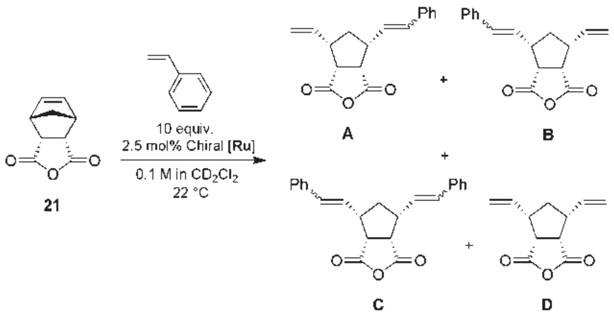


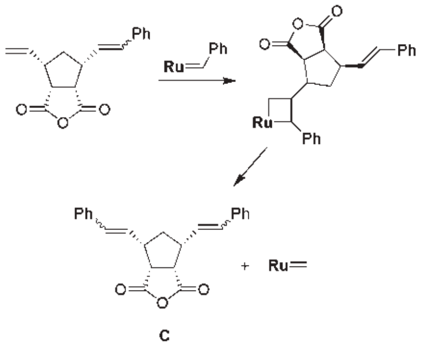
Fig. 2. NHC salts and catalysts synthesized.

of product **C** results in production of a ruthenium methylidene species, regardless of which pathway is taken.



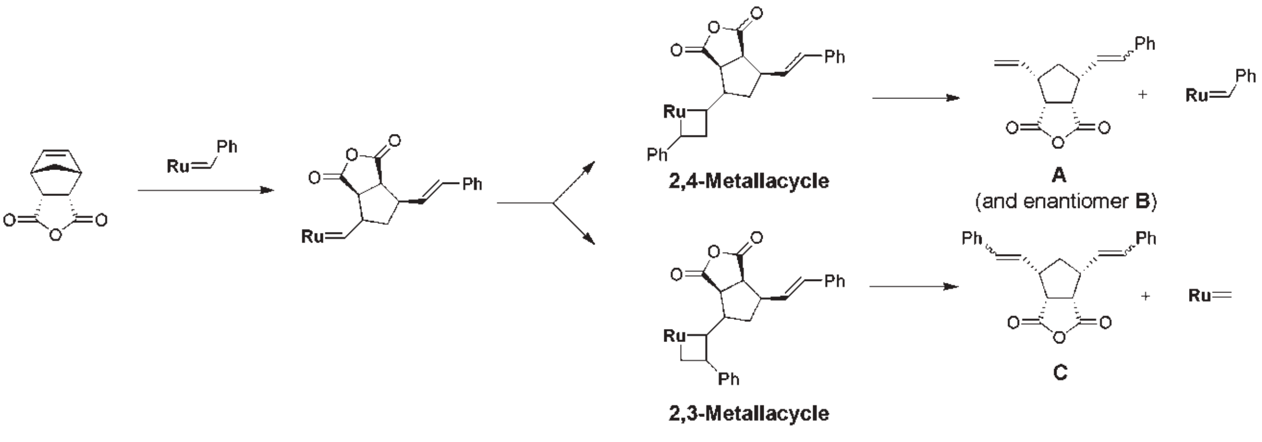
Scheme 3. AROCM catalyzed by ruthenium complexes: observation of side products.

Reaction kinetics can be used to determine the likely pathway through which the catalyst proceeds to generate product **C**. If formation of product **C** is solely the result of secondary metathesis, then the ratio of product **C** relative to products **A** and **B** would be expected to depend on conversion. This would be an indication of the production of **C** depending on the concentration of **A** and **B** in the reaction. With increasing concentration of **A** and **B** (through conversion of substrate), the relative amount of **C** would be expected to increase. Thus, a graph of the ratio of **C** relative to **A** and **B** as a function of conversion should have an upward slope if secondary metathesis were the primary mechanism. However, if formation of **C** were the result of the catalyst proceeding through a 2,3-metallacycle, then the ratio of **C** relative to **A** and **B** would be expected to be constant, reflecting the inherent preference of the catalyst for a 2,4-metallacycle *vs* a 2,3-metallacycle. Thus, plotted as a function of conversion, the ratio of product **C** relative to products **A** and **B** should be a horizontal line.

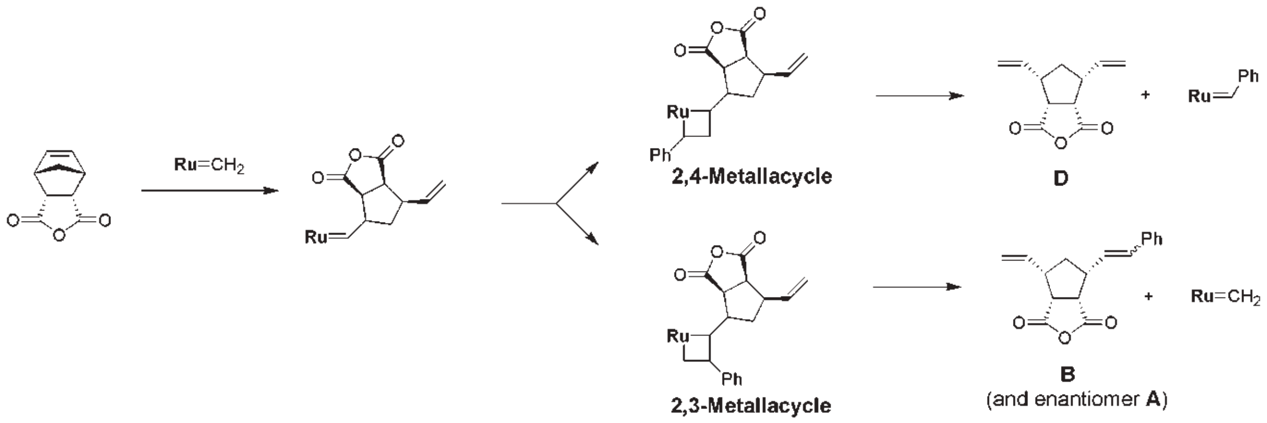


Scheme 5. Mechanism for the formation of product C via secondary metathesis.

Accessing product **D** requires ring-opening of **21** by a ruthenium methylidene species to generate the first terminal olefin, followed by reaction with styrene through a 2,4-metallacycle to give the second terminal olefin (Scheme 6). Product **D** could be formed by the ethenolysis of products **A** and **B**, although this mechanism of forma-



Scheme 4. Mechanism for the formation of product C via a 2,3-metallacycle.



Scheme 6. Formation of product D: ring-opening of 21 via a ruthenium methylidene species.

tion is highly unlikely, considering the low concentration of ethylene in solution. If product **D** were made by the ethenolysis of **A** and **B**, then the ratio of **D** relative to products **A** and **B** would be expected to be dependent on the concentration of ethylene in solution. If the ratio of **D** relative to **A** and **B** is independent of ethylene concentration, then presumably **D** is formed by ring-opening of **21** with a ruthenium methylidene species.

Kinetic studies were carried out with catalyst **15** (Fig. 2) to elucidate the pathways to products **C** and **D**. The ratio of product **C** relative to products **A** and **B** was followed with conversion by proton NMR and is shown in Fig. 3. This ratio is constant (0.16:1.0) up to complete consumption of substrate **21**, indicating that product **C** is formed as a result of formation and breakdown of the 2,3-metallacycle. After complete conversion of substrate **21**, the ratio of product **C** relative to products **A** and **B** increases, indicating that secondary metathesis is occurring, but primarily only after **21** has completely reacted. Hence, during the reaction product **C** is formed as a result of the catalyst proceeding *via* a 2,3-metallacycle, and after the reaction is complete, secondary metathesis of products **A** and **B** generates more product **C** (Fig. 3).

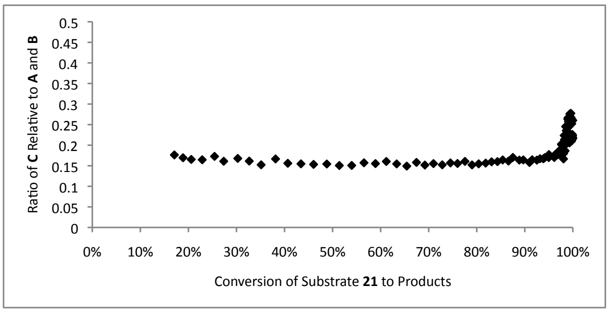


Fig. 3. Ratio of product **C** relative to products **A** and **B** as a function of conversion catalyzed by **15**.

The ratio of product **D** relative to products **A** and **B** was constant as a function of conversion (Fig. 4), suggesting ring-opening of **21** by a methylidene species, followed by reaction of styrene through a 2,4-metallacycle. No dependence was observed on the concentration of ethylene in solution, indicating that ethenolysis of products **A** and **B** is not a major contributing pathway to the formation of compound **D**. Therefore, the production of **D** indicates propagation of a ruthenium methylidene species. This ruthenium methylidene species can be generated by several reactions, including self-metathesis of styrene and formation of product **C**.

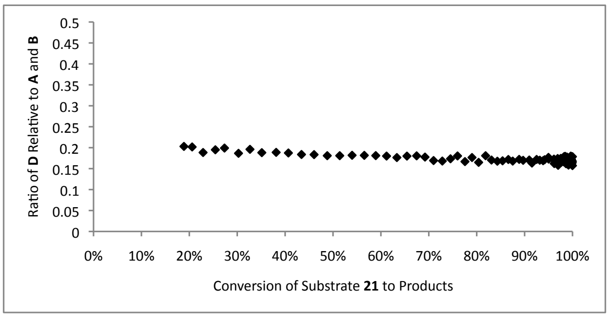


Fig. 4. Ratio of product **D** relative to products **A** and **B** as a function of conversion catalyzed by **15**.

Complexes **16-20** (Fig. 2) were also screened to determine their enantioselectivity and to see if they afforded products **C** and **D** in addition to products **A** and **B**. The reactions were monitored by NMR to determine when they were complete. The mixtures were worked-up immediately to prevent any secondary metathesis from potentially eroding or enhancing the ee of the products. As discussed, complex **15** gave good enantioselectivity at 69% ee of **A** (Table 1, entry 1). Interestingly, **16** gave 14% ee of the opposite enantiomer **B**, despite having the same stereochemistry as **15** (both *S* configuration). The most plausible explanation is that **16** is less enantioselective than **15**; additionally, the ring-opening of **21** by the methylidene species of **16**, followed by formation of the 2,3-metallcycle, occurs at a high enough frequency to ultimately favour enantiomer **B**. Since the methylidene species presumably has the same facial selectivity as the alkylidene species (leading to the formation of the opposite enantiomer of product), (*S*)-**16** could afford **B** as the major enantiomer (Table 1, entry 2), compared to enantiomer **A** yielded by (*S*)-**15**. Complex **17** also gave **B** in 9% ee, probably for the aforementioned reasons (Table 1, entry 3). While the different structural features of the chiral *N*-alkyl groups of the same stereochemical configuration could spatially alter which enantiomer they select for, complexes **15-17** seem similar enough to render this unlikely to be the cause of the difference in the preferred enantiomer.

By comparison to **15**, catalyst **18** showed only moderate enantioselectivity, affording product **A** in 33% ee (Table

Table 1. Enantioselectivity of catalysts **15**-**19** in AROCM of substrate **21**.

Entry[a]	Catalyst	Time (h)	Conv. (%)[b]	Yield (%)[c]	ee (%)[d]
1	**15**	5.5	60	60	69 (**A**)
2	**16**	0.5	99	69	14 (**B**)
3	**17**	0.5	99	73	9 (**B**)
4	**18**	5.5	98	65	33 (**A**)
5[e]	**19**	10.5	98	54	82 (**A**)

[a]Catalyst loading of 2 mol%; [**21**]: 0.2 M in dichloromethane; T: 22 °C. [b]Conversion determined by ^{1}H NMR spectroscopy using disappearance of **21**. [c]Isolated yield. [d]Enantiomeric excess determined by chiral HPLC. [e]Catalyst loading of 3 mol%.

1, entry 4). Complex **19** showed the highest selectivity at 82% ee of **A**, comparable to the best ruthenium catalysts reported to date for this particular substrate (Table 1, entry 5). Although complex **19** (*R* configuration) yields the same enantiomer as complex **15** (*S* configuration), we believe the *N*-alkyl structures are unique enough that a direct comparison between these catalysts cannot be made. Complex **19** was significantly slower than the other catalysts screened, but showed no signs of decomposition throughout the reaction. Only the *trans* products were observed in all cases.

The effect of temperature on enantiomeric excess for AROCM catalyzed by **15** was studied and, as expected, the ee increased with decreasing temperature and decreased with increasing temperature (Table 2). Complex **15** gave up to 72% ee of **A** at 0 °C, and afforded only 42% ee of **A** at 60 °C. The reaction was also noticeably slower at lower temperatures, reaching only 50% conversion after 4 hours at 0 °C, compared to 99% conversion at 50 °C in 3.5 hours.

Table 2. Effect of temperature on the enantioselectivity of 15.

Entry[a]	Time (h)	Temp (°C)	Conv. (%)[b]	ee (%)[c]
1	4.0	0	50	72
2	7.0	22	99	69
3	3.5	40	99	51
4	3.5	50	99	50
5	3.5	60	99	42

[a]Catalyst loading of 2.5 mol%; T: 22 °C; [**21**]: 0.1 M in dichloromethane. [b]Conversion determined by ^{1}H NMR spectroscopy. [c]Enantiomeric excess was determined by chiral HPLC.

Complexes **16**-**20** also gave side products **C** and **D** during the AROCM of **21** (Table 3). Since complex **20** is racemic, its product distribution should not be affected by any potential enantiospecificity of a reaction step. With the exception of complex **19**, the catalysts generated approximately the same amount of product **C** relative to major products **A**/**B**, indicating that the inherent preference for a 2,4-metallacycle *vs* a 2,3-metallacycle is similar for these *N*-aryl, *N*-alkyl NHC catalysts. Complex **19**, however, proceeds almost exclusively by a 2,4-metallacyle, as shown by its low ratio of **C** to **A** and **B** (0.08:1). The ratio of product **D** relative to products **A** and **B** varied significantly for the different catalysts. Complex **19** gave an unusually high ratio of product **D** relative to **A** and **B** (0.43:1), suggesting that this complex has a high propensity to propagate *via* a methylidene species (Table 3, entry 5).

Table 3. The amount of side products C and D formed by different catalysts.

Entry[a]	Catalyst	Time (h)	Conv. (%)[b]	%**C**[c]	%**D**[d]
1	**15**	1.0	99	16	12
2	**16**	0.5	99	15	19
3	**17**	0.25	99	14	23
4	**18**	1.0	99	12	18
5	**19**	6.0	82	8	43
6	**20**	0.5	99	17	18

[a]Catalyst loading of 2.5 mol%; [**21**]: 0.2 M in dichloromethane. [b]Conversion determined by ^{1}H NMR spectroscopy. [c]Percent **C** relative to **A** and **B**. [d]Percent **D** relative to **A** and **B**.

In order to confirm that product **C** was being formed as a result of the catalysts proceeding *via* a 2,3-metallacycle as a general principle, and not unique to complex **15**, the ratio of **C** relative to **A** and **B** was plotted as a function of conversion for catalysts **17**, **18**, and **20** as well. In all cases, the ratio of **C** to **A** and **B** was constant up to complete consumption of substrate **21**, after which secondary metathesis occurred to increase the amount of **C** in the reaction mixture. Similarly, the ratio of product **D** to products **A** and **B** was shown to be constant throughout the reaction, confirming that these pathways are general to the complexes investigated in this study.

The ratios of **C** to **A**/**B** and **D** to **A**/**B** were calculated as a function of temperature in order to determine the effect of temperature on alkylidene *vs* methylidene propagation and the formation and breakdown of the 2,4-metallacycle *vs* 2,3-metallacycle. Complex **15** was used as the catalyst at a loading of 2.5 mol%, and the respective ratios were determined upon completion of the AROCM of **21** (0.1 M in dichloromethane) by proton NMR spectroscopy. With higher temperature, the amount of both products **C** and **D** formed in the reaction increased (Fig. 5). This is possibly a result of the higher temperature providing the necessary energy for the reaction to proceed down the less favourable pathways, thereby giving more of the end-products of those pathways, **C** and **D**.

Conclusion

Complexes **15**-**20** yield side products during AROCM reactions resulting from the catalysts proceeding through a 2,3-metallacycle in addition to a 2,4-metallacycle, as well as propagating by a methylidene species, and these pathways were found to be general to this class of ruthenium catalysts investigated. The inherent preference of a given catalyst for the formation and breakdown of a 2,4-metallacycle *vs* a 2,3-metallacycle affects its product distribution, and this catalyst behaviour can be utilized to target products and particular applications. It also can be considered in new catalyst design, as the ligand structure was shown to have an effect on the propensity of the catalyst to undergo a 2,3- *vs* 2,4-metallacycle. Similarly, high pref-

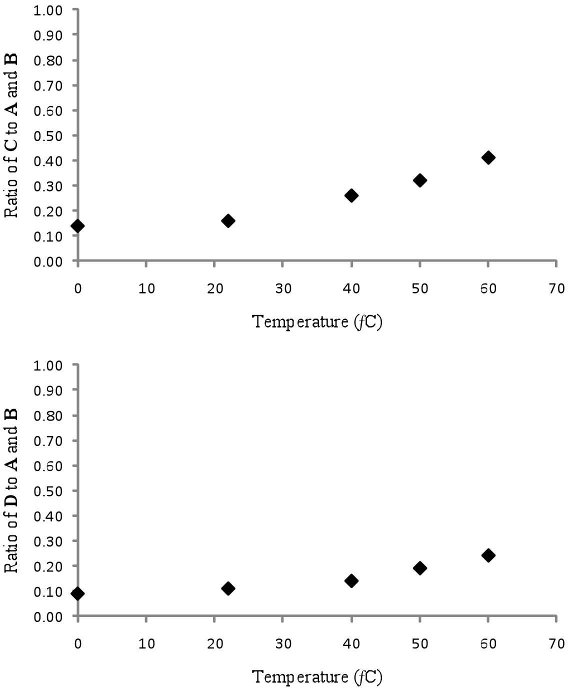


Fig. 5. Effect of temperature on the conversion to products **C** and **D**.

erence for methylidene propagation alters product ratios and can be used for applications where this is a desirable pathway. Additionally, methylidene propagation generally shortens catalyst lifespan, a necessary consideration in the choice of catalyst for a given reaction. Catalysts **15** and **19** gave high enantioselectivities, with catalyst **19** showing comparable enantioselectivity to the best ruthenium catalysts reported to date. Future research directions are focused toward exploited these catalyst properties for targeted reactions.

Experimental Section

General Considerations

All manipulations of air- or water- sensitive compounds were carried out under dry nitrogen using a glovebox or under dry argon utilizing standard Schlenk line techniques. NMR spectra were recorded on a Varian Mercury (^{1}H, 300 MHz), Varian Inova 400 (^{1}H, 400 MHz), or a Varian Inova 500 (^{1}H, 500 MHz; ^{13}C, 125 MHz) spectrometer and referenced to residual protio solvent. Enantiomeric excesses were determined by chiral HPLC. Column: chiralcel AD; Solvent system: 8% isopropanol in hexanes. Flow rate: 0.75 mL per min.

Materials

Deuterated dichloromethane was dried over calcium hydride and vacuum distilled, followed by three cycles of freeze-pump-thawing. *cis*-5-norbornene-*endo*-2,3-dicarboxylic anhydride (**21**) was obtained from Aldrich and used without further purification. Styrene was purchased from Aldrich and filtered through a silica gel plug prior to use.

Representative AROCM reaction of cis*-5-norbornene-*endo*-2,3-dicarboxylic anhydride with styrene.*

Substrate *cis*-5-norbornene-*endo*-2,3-dicarboxylic anhydride (60 mg, 0.36 mmol) was added to a 100 mL round bottom flask containing a vacuum adaptor, and the flask was placed under an argon atmosphere. Dry dichloromethane (6 mL) was added *via* syringe, followed by styrene (0.42 mL, 3.6 mmol). Catalyst **15** (6.5 mg, 2.5 mol%) was then added, and the reaction was stirred for 4 h. The mixture was concentrated, and a proton NMR taken to calculate the relative ratios of products **A**/**B**, **C**, and **D**. The products were purified by column chromatography (silica gel, 50% ether in pentane). Stillbene came off with an R_f of 0.91. Product **D** came off with an R_f of 0.43 and was recovered in trace amounts. Product **A**/**B** had an R_f of 0.33 (49 mg, 47% yield) and product **C** had an R_f of 0.27 (12 mg, 10% yield). Enantiomeric excess was determine by chiral HPLC, with enantiomer **A** showing a retention time of 28.95 min, and enantiomer **B** showing a retention time of 32.98 min. Product **A** was obtained in 69% ee over product **B**. The enantiomers were identified by comparison to the retention times under the same chiral HPLC conditions outlined in reference 14.

^{1}H NMR of product **A**/**B** ($CDCl_3$, 500 MHz): δ 7.42–7.35 (m, 2H), 7.35–7.29 (m, 2H), 7.25–7.21 (m, 1H), 6.52 (d, J = 15.8 Hz, 1H), 6.30 (dd, J = 15.8, 8.0 Hz, 1H), 6.03–5.90 (m, 1H), 5.23 (d, J = 1.1 Hz, 1H), 5.20 (dt, J = 7.5, 1.3 Hz, 1H), 3.61–3.47 (m, 2H), 3.22–3.11 (m, 1H), 3.10–2.99 (m, 1H), 2.14 (dt, J = 12.8, 5.5 Hz, 1H), 1.57 (q, J = 12.9 Hz, 1H) ppm. ^{13}C NMR of product **A**/**B** ($CDCl_3$, 125 MHz): δ 170.79, 136.84, 134.99, 132.48, 128.81, 127.96, 126.68, 126.57, 117.62, 50.06, 49.62, 47.00, 46.43, 36.78 ppm.

^{1}H NMR of product **C** ($CDCl_3$, 500 MHz): δ 7.39 (m, 4H), 7.35–7.29 (m, 4H), 7.24 (m, 2H), 6.55 (d, J = 15.8 Hz, 2H), 6.31 (dd, J = 15.7, 8.0 Hz, 2H), 3.63–3.56 (m, 2H), 3.22 (m, 2H), 2.22 (dt, J = 12.7, 5.4 Hz, 1H), 1.66 (q, J = 12.9 Hz, 1H) ppm. ^{13}C NMR of product **C** ($CDCl_3$, 125 MHz): δ 170.77, 134.98, 132.55, 128.82, 127.98, 126.70, 126.54, 50.00, 46.57, 37.55 ppm.

^{1}H NMR of product **D** ($CDCl_3$, 500 MHz): δ 6.01–5.91 (m, 2H), 5.23–5.20 (m, 2H), 5.19 (dt, J = 10.0, 1.2 Hz, 2H), 3.54–3.44 (m, 2H), 3.06–2.94 (m, 2H), 2.07 (dt, J = 12.9, 5.5 Hz, 1H), 1.49 (q, J = 13.0 Hz, 1H) ppm. ^{13}C NMR of product **D** ($CDCl_3$, 125 MHz): δ 170.74, 135.00, 117.59, 49.68, 46.90, 36.04 ppm.

Representative kinetic experiment for the pathway to the formation of products C and D.

In a nitrogen atmosphere glovebox, an NMR tube was charged with *cis*-5-norbornene-*endo*-2,3-dicarboxylic anhydride (20 mg, 0.12 mmol) and 0.5 mL of deuterated dichloromethane. The NMR tube was sealed with a septum cap and brought out of the glovebox. Styrene was added via syringe through the septum cap, and a proton NMR spectrum (CD_2Cl_2, 500 MHz) was taken for time = 0. An NMR array was set up with pad increments of 10 sec, 16 scans per spectrum, 200 spectra. Catalyst solution (**15** in 0.25 mL dry CD_2Cl_2; 1.7 mg, 2 mol%) was injected by syringe into the NMR tube, and the sample was inserted into the spectrometer. The data were collected and analyzed using MestReNova software.

Acknowledgement

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2011 International Year of Chemistry

Calendar of Events

2011 C CHEMISTRY International Year of CHEMISTRY 2011

April

Molecular Anthology Project continues (submissions end)

May

Chemistry in Fibre Project begins (through the RSNZ)

Molecular Anthology Project (Voting)

July

ChemEd conference in Palmerston North (July 17-20)

Nature of Science Series begins (with the RSNZ)

Molecular Anthology Project Completed – Presentation at ChemEd Conference

August

RadioNZ lecture series

September/October

Prof Bob Grubbs, 2003 Nobel Laureate, Erskine Fellow in residence at University of Canterbury

November

2011 Research Honours Dinner

Elemental Project concludes

December

NZIC Conference in Hamilton

Exhibition of Elemental Project at NZIC Conference

***Up-to-date information will be posted on the NZ website:* www.yearofchemistry.org.nz**

TAML Activators: Green Chemistry Catalysts as Effective Small Molecule Mimics of the PeroxidaseEnzymes

Terrence J. Collins

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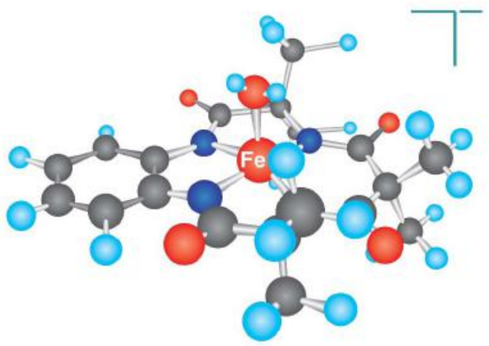
About the Author

Terry Collins, a New Zealander by birth, gained his chemistry education at Auckland University, completing his PhD under the guidance of Prof. Warren Roper in 1978. After a postdoctoral with James Collman at Stanford he was appointed Assistant Professor at CIT and then moved to Carnegie Mellon University in 1988, where he is now the Teresa Heinz Professor of Green Chemistry. Terry championed the field of green chemistry and gained international recognition for his work in creating a new class of oxidation catalysts with enormous potential and positive impact on the environment. Experts worldwide believe that Collins' commercializing systems can be used to effectively replace chlorine-based oxidants in large global technologies so that some of society's most toxic chlorinated residuals are not produced. The systems also enable valuable approaches for handling previously unsolved environmental and health problems. His honors include the EPA's 1999 Presidential Green Chemistry Challenge Award, the Pittsburgh Section Award of the ACS and Japan's Society of Pure and Applied Coordination Chemistry Award. Terry is an Honorary Professor and a Distinguished Alumni awardee of Auckland University. He was the inaugural recipient of the Kaufman Award of Pittsburgh Foundation and he received the 2010 Heinz Award for his green chemistry work. He was elected an Honorary Fellow of the RSNZ in 2008.



Terry learned of the insidious health damage caused by pollutants from paper and pulp mills and pesticides in his native New Zealand. He began exploring whether there could be an environmentally benign and cost-effective new technology to avoid or to destroy the pollutants. After a major breakthrough in homogeneous catalyst ligand design, Collins and his fellow researchers established the scientific basis for both goals and more. Laboratory studies show that oxidation processes employing hydrogen peroxide can now be used to avoid and eliminate pollutants in these and other industries. Commercialization is under way and there are application areas still to be discovered. The ongoing saga of deleterious health effects in New Plymouth is but one reason to bring him home fairly frequently.

Introduction

It is now over 30 years since I received my Ph.D. degree from the University of Auckland where I was privileged to receive a world-class training from Warren Roper, New Zealand's world-leading organometallic chemist, and to be a contemporary of current Auckland staff members, James Wright and Penny Brothers. We are a few of the lucky chemists to have been students of Professor Roper.

In this short review, I will give a perspective on my independent research that started in 1980 and led, in 1995, to TAML® activators (see Chart 1), the first effective small molecule mimics of the peroxidase enzymes. And I will sketch our ongoing studies of their further design, mechanisms of action and applications. In the last two decades, I have become increasingly inspired by the potential of green chemistry to help in building the technological dimension of a sustainable civilization and I will weave green chemistry into the discussion.

Green chemistry was launched at the US Environmental Protection Agency (USEPA) in 1991. Dr. Paul Anastas proposed the important definition a few years later, namely: *Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances*. When green chemistry arrived on the scene, my program to develop miniature peroxidase replicas fitted into the infant field perfectly. My long-term goal was to develop oxygen- or peroxide-based processes that could replace chlorine and metal-based oxidations in water and elsewhere. While these incumbent oxidation technologies bring us many benefits, they also come at the cost of adding carcinogens and/or other toxic pollutants to water and, thus, can be viewed as temporary rather than as sustainable solutions for the important process goals they meet.

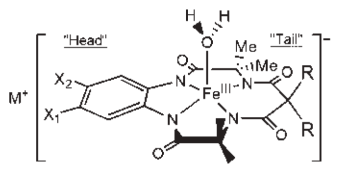
While in New Zealand, I learned a lot about the controversial subject of dioxin toxicity. My evaluation as a young scientist, listening to and reading the dioxin debates of the 1970s, was that what I will call the environmentalist point of view (for want of a better terminology) was probably correct—dioxin contamination of the herbicide 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) was leading to exposures resulting in much human illness and even severe developmental abnormalities in NZ infants. Over the years, more and more information concerning dioxin toxicity has come to light about what was known and when it was known. While this is not the right place to air all the details, the well-documented history is both a sorry story and an emblem of what needs to be avoided in industrial chemistry if we are going to build a sustainable civilization. We are burdened today with large-scale, unsustainable products because *dioxin* (or more appropriately *dioxins* to capture all the toxic dioxins and dioxin-like compounds) has been poorly handled since the 1960s. And I have come to realize that how each generation responds to challenges like dioxins plays a large role in determining whether our civilization gets more sustainable or less sustainable on that generation's watch.

As soon as green chemistry emerged, my team and I were happy to call ourselves *green chemists* and to join with Dr. Anastas and other colleagues to help expand our own and general understanding of what this field, which is so critical to a good future for mankind, has to become. You can learn more about important concepts of green chemistry and especially (at this stage of development) about introductory materials on the multidisciplinary understanding that is vital to green chemistry's success by visiting Carnegie Mellon's open-source green science education website (see: *http://igs.chem.cmu.edu/*).

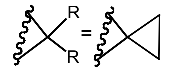
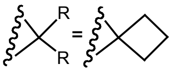
The Design Problem for Peroxidase Mimics and Green Chemistry Connections

In biochemistry, oxidation processes are largely carried out by oxygen or its reduced derivative, hydrogen peroxide (which living things produce from oxygen). Oxygen and hydrogen peroxide possess very complex chemistries that are mostly marshalled by iron-based enzymes. These enzymes have proven to be particularly difficult to mimic with small molecule catalysts, in large part because the reactive intermediates produced when peroxide is mixed with activating metal species are aggressively oxidizing and readily destroy oxidizable ligands. Enzymes use their proteins to provide protection to metalloprotein ligands in various ways. For large-scale water purification processes, toxicity has to be avoided and this severely restricts the metals that can be used. Iron is ideal. It is widely used in biochemistry and, coincidentally, it is the least toxic transition metal. By following an iterative design protocol for fifteen years that was aimed at slowing down oxidative and hydrolytic ligand degradations in potential small molecule catalysts, we were able to develop TAML® activators with iron as the active metal (Chart 1). TAML activators have genuinely useful lifetimes and we have since shown that they are quite faithful mimics of the peroxidase enzymes.[1,2] In the process, we produced a set of rules to guide co-ordination chemists wanting to produce oxidation resistant ligand systems.[3]

Chart 1. First generation TAML activators with iron as the active metal.



1

1	X$_1$	X$_2$	R
a	H	H	Me
b	Me	Me	Me
c	Me	H	Me
d	MeO	MeO	Me
e	NO$_2$	H	Me
f	COOMe	H	Me
g	COOH	H	Me
h	CONH(CH$_2$)$_2$NMe^{3+}	H	Me
i	Cl	Cl	Me
j	Cl	Cl	Et
k	Cl	Cl	F
l	H	H	F
m	H	H	
n	Cl	Cl	

Catalytic Properties of TAML Activators

TAML activators are able to mimic peroxidase processes very well for two key reasons. Firstly, anionic amido-*N* ligands possess a high donor capacity. With four such Lewis bases, the TAML macrocycle shifts iron's redox chemistry with hydrogen peroxide away from the outer sphere processes called *Fenton chemistry* to inner sphere processes in which the metal is relatively easily oxidized by one and two units above the ferric (Fe^{III}) state with concomitant formation of oxo ligands. So for example, in terms of reduction potentials, iron(IV) in the TAML environment looks like iron(III) in the porphyrin environment. Secondly, the macrocycles have been iteratively designed to resist the oxidative degradation pressure that has probably terminated prior attempts to mimic peroxodase-like catalysis—this designed-in resistance to oxidative destruction is the real key to the functional lifetime of TAML activators.[4,5]

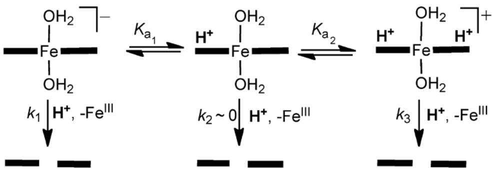
TAML activators catalyze peroxide processes typically at room temperature under ambient conditions. The five coordinate structures isolated in the solid state from the syntheses (Chart 1) – sometimes axial chloride complexes are produced – form six-coordinated species in water with two axial water ligands. The very high donor capacity of the macrocycles significantly quenches the axial Lewis acidity of the iron and this has the benefit of making the axial ligands particularly labile to deliver a significant advantage for catalysis. Luckily, our use of high donor capacity ligands with iron did not overly mute the oxidizing properties (a perceived risk at the outset of the project), but instead produced very reactive catalysts. In contrast, we made the first manganese(V)-oxo complexes many years ago and found these to be remarkably inactive. We attributed the low reactivity to the high donor capacities of the polyanionic chelating ligand systems we were developing at that time.[6-8]

Hydrolytic Stability

The hydrolytic stability of any catalyst intended for use in water is a critical property. The prototype TAML activator, **1a**, is stable in water under neutral pH. However, under acid conditions, H^+-promoted demetalation occurs that follows the rate law:[9]

$$k_{obs} = k_1{*}[H^+] + k_3{*}[H^+]^3.$$

This rate law is consistent with the mechanism in Scheme 1 provided that K_{a1} and K_{a2} are high, ensuring $K_{a1}K_{a2} >> (K_{a2}[H^+] + [H^+]^2)$ and k_2 is negligible compared to k_1 and k_3.[9]



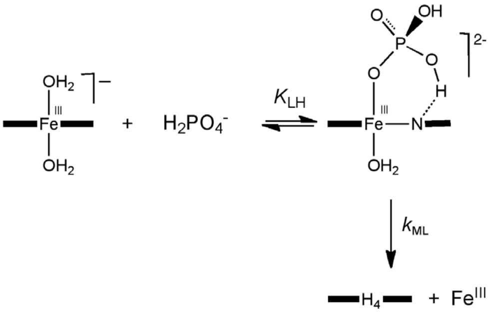
Scheme 1. Suggested mechanism of the H+-induced demetalation; ▬ ▬ = macrocyclic ligand; see ref. 9

So we had to ask where the protons might be attaching to the TAML activator in the demetalation processes and we concluded that amide ligand nitrogen and oxygen atoms were the likely binding sites. The third order term is intriguing as it requires three protons to attach somewhere before the metal is liberated. We suspected that protonation of the tail amide oxygen atoms (see Chart 1) was involved. This suggested that we could slow the rate of demetalation by reducing the basicity of the tail region. We achieved this by replacing the methyl substituents on the six-membered chelate ring with fluorine groups and were able to dramatically lower the demetalation rate constants validating a strategy for producing acid-tolerant TAML activators.[9]

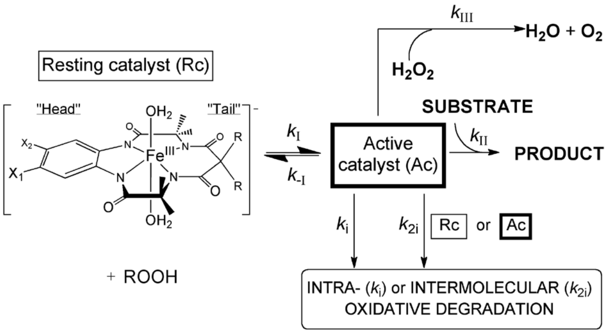
We also found that in the pH 4–9 region, certain buffer ions would lead to the slow demetalation of acid-intolerant TAML activators and others would not. A mechanistic study led us to the conclusion that if a buffer ion can bind to the axial site of the TAML catalyst to set up a six-membered ring for delivery of a proton to an amide nitrogen atom, then an enhanced rate of demetalation will occur (Scheme 2).[10] The message for applications chemistry is that if solutions of TAML activators are to be stored for long periods, buffer ions that can form these proton-delivering rings should not be present.

The Mechanisms of TAML Activator Catalysis

TAML activators catalyze the reactions of hydrogen peroxide to oxidize a broad range of substrates. We have spent much time studying the mechanisms and this work has been reviewed recently.[11,12] The overall mechanism is summarized in Scheme 3.



Scheme 2. Mechanism of dihydrogenphosphate-induced demetalation of TAML activators.



Scheme 3. Overall mechanism of peroxide catalysis by TAML activators.

The resting catalyst is a six coordinate ferric species. It interacts with peroxides (usually hydrogen peroxide is employed) to produce the active catalyst (**Ac**). By performing syntheses in liquid organic solvents at low temperature (-60 °C), we have produced an iron(V)-mono-oxo complex in almost pure form.[13] It is the first such species to be discovered and is low spin with one unpaired electron residing in a π* orbital of the iron-oxo bond. The oxo complex decays at higher temperatures such that we are not able to look for its possible formation in water, the key solvent for most of our studies and the vital medium for environmental applications. Iron(IV)-oxo complexes have also been produced in aqueous solution[14,15] and these are clearly involved as intermediates in catalysis to varying degrees depending upon the conditions. At this stage of our understanding, **Ac** should be considered to represent a number of possible reactive intermediates that form singly or multiply depending on the reactions conditions. Once formed, the **Ac** species then engage in a series of reaction processes that determine the effectiveness of the catalysis. Many reactions come into play in the catalytic cycle.

Firstly, there is a peroxidase-like reaction pathway in which **Ac** interacts with an oxidizable substrate. Depending on the substituents on the TAML macrocyle, the catalysts provide relatively more or relatively less aggressive peroxidase-like oxidizing systems. Secondly, **Ac** may catalyze a catalase-like process in which the peroxide is decomposed.[16] Hydrogen peroxide is more sensitive to this reaction channel than organic peroxides and it is decomposed to oxygen and water. Fortunately, the catalase-like chemistry, which is wasteful of hydrogen peroxide, does not dominate over the peroxidase-like chemistry, at least for the many substrates we have studied in detail to date. But when TAML/peroxide media do not attack hard-to-oxidize oxidizable substrates, competition from the catalase process might be significantly responsible for the inactivity.

Thirdly, **Ac** engages in catalyst degradation processes. Two classes of degradations, intramolecular (k_i) and intermolecular (k_{2i}), have been identified. The rates of two separate intramolecular processes have been determined and some level of mechanistic insight has been obtained.[17] The bimolecular process(es) is(are) the subject of ongoing studies. The fact that TAML activators degrade in use is a plus for the environmental performance. Nature has developed enzymes to possess limited lifetimes. Industrial catalysts that are to be released to the environment as part of the operation of a technology should be designed similarly. Other reactions occurring, either before or after the production of **Ac**, also exert an influence on the catalysis. Thus, fourthly, a series of dimeric complexes have been detected and one of these, an oxo-bridged Fe(IV)–O–Fe(IV) dimer, has been reported.[14] The Fe(IV)–O–Fe(IV) reversibly hydrolyzes into two Fe(IV)(O) complexes depending upon the pH. There is much that remains to be understood about the significance of these various species in the overall catalytic cycle. Remarkably, in non-coordinating solvents, the Fe(IV)–O–Fe(IV) complex forms rapidly and completely from the ferric TAML activator and dioxygen. This opens the possibility of using TAML activators in oxygen-based oxidation processes.[18] Indeed, the ferric TAML activator does slowly catalyze oxygen-based oxidations of organic substrates in non-coordinating solvents, but heating is required and the challenge has become one of redesigning the TAML activator such that the same high quality of catalytic performance can be enabled for oxygen as has been found for peroxide. Oxygen chemistry is receiving much attention in my group at present.

Fifthly, one of the most interesting properties of the catalytic behaviour is its pH dependence, an effect that is manifested in the production of **Ac**.[16] Under conditions where the formation of **Ac** is rate determining, the peroxidase-like activity at room temperature changes by a factor of more than 10 over a range of 5 to 6 pH units. As the pH is increased from neutral, the rate soon begins to increase. It reaches a maximum value at about one half a pH unit above the pK_a of the TAML activator [an iron(III)bis(aqua) complex] that is being used. After reaching a maximum, the rate then declines as the pH is raised further. The catalase-like activity similarly varies with pH and reaches a maximum at the same pH value as the peroxidase-like activity. The p*K*a values for first generation TAML activators lie between 9.5 and 10.5.[16] Similar behaviour is found for organic hydroperoxides, but the curve shifts as the peroxide is changed, with the maximum rate moving to higher pH as the pK_a of the peroxide increases.[15] Following much mechanistic analysis of numerous catalysts, we have interpreted the data to mean that the rate of formation of the reactive intermediates depends on the state of deprotonation of both the iron(III)bis(aqua) complexes and the peroxides. The greatest rate occurs when the mono-deprotonated catalyst interacts with the neutral peroxide. For use in real-world processes, the closer the maximum rate is to neutral pH, the more useful the catalyst is likely to be. Therefore, we are designing TAML activators to have lower pK_a values for deprotonation of the aqua ligands to move the maximum catalytic activity closer to neutral pH. In the family of first generation TAML activators, the most reactive oxidizers have geminal fluorine atoms on the tail six membered chelate ring (R, Chart 1).[20] So if these were to be employed in large scale water treatment, fluoride or persistent organofluorine fragments could be added to water with possible implications for adverse health and environmental effects. In second generation TAML activators, we have learned how to achieve the high reactivity without using fluorine.[20]

One of the most important challenges green chemists must face in designing safer products and processes is to learn how to avoid endocrine disruptors (EDs) or endocrine disrupting chemicals (EDCs)—both names are commonly used. There are several definitions and the following is that of the International Program on Chemical Safety (IPCS; March, 1998): *An endocrine disrupter is an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub)populations.* Endocrine disruptors can alter development at environmentally relevant concentrations, concentrations to which people are being exposed, to result in impaired organisms. An excellent expanded explanation can be found in the Scientific Statement on EDs by the Endocrine Society.[19] Thus, to explore the possibility that TAML activators might have endocrine activity (more precisely, the hope that they would not) we have begun to collaborate with the group of Bruce Blumberg in the Department of Developmental and Cell Biology at UC-Irvine. In the first studies, our colleagues have found that over a wide concentration range (1×10^{-5} M, 1×10^{-6} M, …, 1×10^{-11} M) three different TAML activators do not activate any of three nuclear hormone receptors, *viz*., human thyroid receptor (TRβ), human estrogen (ERα), and rat androgen receptor (AR), suggesting that the catalysts do not bind to the receptors and reducing concerns that the catalysts might have endocrine-disrupting activity.[20]

The Science of TAML Activator Applications

TAML activators have a wide range of laboratory-demonstrated applications several of which are being deployed commercially. In the following discussion, I will sketch a few examples and the reader is referred to a larger recent review for more details and specifics of other systems.[11] The Carnegie Mellon University spin-off company, GreenOx Catalysts, Inc., is leading the commercial development efforts. Groups led by James Wright at Auckland University and Trevor Stuthridge at the Scion Crown Research Institute in Rotorua are among those involved in developing commercial applications.

Because of my interests in the hazard reduction goals of green chemistry, we have focused in research significantly on the remarkable ability of the catalysts to activate hydrogen peroxide to degrade recalcitrant oxidizable pollutants in water and to kill hardy pathogens. A long list of compounds has been shown to be readily degradable. To date, a range of toxicity tests have shown no toxicity problems: luminescent bacterial toxicity assays, tests with Daphnia magna, tests with human cancer cells, and endocrine disruption assays. The studies were conducted, where appropriate, on TAML activators, their degradation products, and aqueous TAML-peroxide reaction solutions after the process of decomposing a pollutant had been completed. However, as time goes on and resources permit, we hope to expand our toxicity testing to more elaborate assays to further consolidate our understanding and to keep checking up on our hopes that the systems are free of toxic properties.

We have tested scores of dyes, including members of each of the main classes; all are degraded. Organophosphorus (OP) triesters account for an estimated 34% of worldwide insecticide sales and are linked to human health and environmental concerns associated with cholinergic toxicity. Some OP insecticides are EDCs. Hydrolytic detoxification approaches for OP insecticides are inadequate, because these do not satisfactorily eliminate the toxicity of the hydrolysates. The complete degradation of a series of widely used OP pesticides has been achieved using TAML/peroxide in a controlled, rapid, versatile, and environmentally friendly manner (on the basis of aquatic toxicity assays).[21] The organophosphorus chemical warfare agents, Soman and VX, are also subject to efficient degradation by TAML/peroxide. Experiments with the *live agents* were conducted at the US Navy's Surface Warfare Center in Dahlgren, VA, when TAML activators demonstrated the highest reactivity and stability in an evaluation of over a dozen different catalysts in combination with several different peroxygen compounds.[22]

The synthetic estrogen, 17α-ethinylestradiol (EE$_2$, Chart 2), is an active ingredient in the birth control pill. It is excreted to give an important source of estrogenicity in water. Farm animals excrete natural estrogens. When large numbers are grouped together in concentrated animal feeding operations (CAFOs) increased estrogenic activity in the surrounding surface waters can result.[23] The commercially available prototype TAML activator 1a (a relatively less aggressive oxidizer in the TAML activator family) at 83 nM with hydrogen peroxide at 4 mM (<2 times the mineralization requirement) has been shown to rapidly degrade 17α- and 17β-estradiol (E$_2$), estriol (E$_3$), estrone (E$_1$) and 17α-ethinylestradiol (EE$_2$) (all at 80 μM, Chart 2), with half-lives of approximately five minutes coinciding with the removal of estrogenic activity.[24] Under these conditions, a kilogram of **1a** could be used to treat more than 20,000 tonnes of water.

Chlorophenols are significant pollutants. The EPA has listed five chlorophenols as priority pollutants, including 2,4,6-trichlorophenol (2,4,6-TCP) and pentachlorophenol (PCP)—pollutants regulated under the Clean Water Act are classified as *priority* pollutants in the US. Chlorinated phenols are resistant to microbiological degradation and can persist for decades in the environment.[25] TAML activators **1a** and **1k** (a relatively aggressive oxidizer in the TAML activator family) were used to catalyze the H_2O_2 treatment of 2,4,6-trichlorophenol and pentachlophenol.[26]

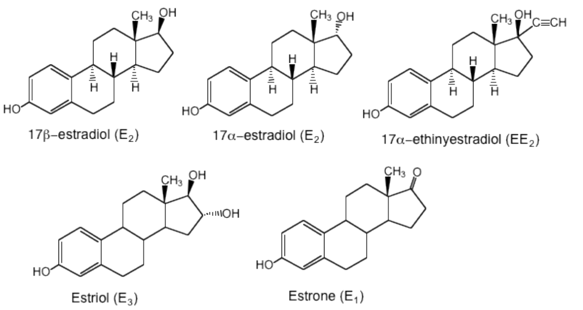


Chart 2. **1a**/H_2O_2 treatment of estrogenic steroid hormones results in their degradation with associated loss of estrogenic activity.

Both compounds were degraded completely in minutes, even by **1a**. The conditions for pentachlorophenol (PCP) were: **1a** (7 μM), PCP (715 equiv., 5 mM), H_2O_2 (100,000 equiv., 0.5 M). The peroxide quantity was not optimized, but at the end of the reaction, the remaining peroxide was assayed for both PCP and TCP and it was found that only slightly more than the mineralization requirement was consumed. The mineralization of PCP requires nine equivalents of hydrogen peroxide. The 25 °C reaction was stopped at 9 minutes by adding acid to eject iron from **1a**. All the pentachlorphenol was gone. Approximately half the carbon was mineralized. The chloride was mineralized to 87±4%. The remainder of the material was mostly small molecule diacids, chlorinated and nonchlorinated. No dioxins were produced within the limits of detection of the mass spectrometers at the Institut für Ökologische Chemie in Neuherberg, Germany.

Among pathogenic microbes, bacterial spores are the hardiest. Most of us know that certain bacterial spores can be extremely dangerous because of the extensive media coverage of the anthrax attacks in the United States in 2001 and their aftermath. We have studied the ability of TAML activator/peroxide to deactivate spores of *Bacillus atrophaeus*, common non-toxigenic surrogates of *B. anthracis* that also serve as indicators for water-borne protozoa such as *Cryptosporidium parvum*. This protozoan is a bane of drinking water treatment plants. Treatment of *B. atrophaeus* with **1k** (50 μM) in the presence of *t*-butylhydroperoxide (TBHP, 0.5 M) and cetyl trimethyl ammonium bromide (CTAB, 0.03%) at pH 10 achieved the military performance goal of a 7 log kill in 15 min.[27] The ability of TAML catalysts to activate TBHP in the presence of CTAB for the decontamination of bacterial spores was studied independently by the Setlow Group at the University of Connecticut employing *Bacillus subtilis* spores where similarly efficient (and lethal) deactivation was observed.[28]

Conclusion

At nanomolar catalyst concentrations, TAML® activators effectively and efficiently mimic the activity of peroxidase enzymes. The catalysts represent a case study in green chemistry because they activate hydrogen peroxide, an oxidant that is used profusely in biochemistry, to decompose persistent pollutants and hardy pathogens in water. Many applications for cleaning water of recalcitrant pollutants and hardy pathogens have been demonstrated in the laboratory. The mechanisms of action are becoming well understood. Based on the toxicity data collected to date, it is appropriate to call TAML® activators *green oxidation catalysts*. Several applications are in commercial use. The catalysts possess the technical properties to offer a potent new tool for water-based oxidations and advanced water purification processes.

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ChemScrapes

Augustus Kekule's hitherto unreported rotaxane dream.

Brendan Burkett

We Need to Know More about Atmospheric Chemistry

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About the Author

Martin Manning, BSc, MSc (Hons.), PhD (McMaster), ONZM, has been involved with climate change science for the past thirty years. After gaining his PhD degree from McMaster University in Canada he worked as a theoretical nuclear physicist in that country, in the UK and NZ, where he moved into climate change research. At NIWA he led research programs covering atmospheric chemistry and the carbon cycle for some ten years and represented NZ on the Intergovernmental Panel on Climate Change (IPCC). This led to his spending five years in Colorado managing the recent IPCC assessment of the physical science of climate change prior to that organization being awarded the 2007 Nobel Peace Prize. He has been involved in World Meteorological Organisation committees, and a member of the Scientific Steering Committee of the International Global Atmospheric Chemistry. He returned to NZ in early 2008 to become Director of Victoria University's Climate Change Research Institute, with responsibility for the interdisciplinary climate change study. He gained national honours in 2008, being made an Officer of the New Zealand Order of Merit.

Introduction

Our understanding of global environmental change has gone through many stages of steady accumulation of information followed by sudden realisation that things are happening more rapidly or more extensively than expected. Here I want to argue that it is now becoming important to carry out research that will anticipate potentially serious changes in atmospheric chemistry to a greater extent than we have done so far.

The most recent example of our starting to understand that global changes can be more rapid than was initially expected has come from observations of accelerating changes in the Greenland and Antarctic ice sheets. In 2006, when I was heavily involved along with other lead authors in finalising the Fourth Assessment of Climate Change for the Intergovernmental Panel on Climate Change (IPCC), it had become clear that the observed increasing rates of sea level rise and melting of glaciers and ice sheets were starting to look inconsistent with projections for future sea level rise.

Because there was a lack of scientific literature covering what these new rates of change could mean for this century, all we could do was to include a statement about sea level having been higher by about 6 m the last time that the Earth became significantly warmer than it was now.[1] A major advance in our understanding of sea level rise came soon afterwards with a much better explanation of the changes that had occurred since 1961.[2] This showed that not only could the entire rise be attributed to the effects of climate change, but that about 60% was now due to the widespread melting of glaciers and the accelerating loss of major ice sheets. It contrasted very strongly with the previous climate model projections for future sea level rise that had been based on assumptions that, even by 2100, only about 20–25% of sea level rise would be due to ice sheet and glacier loss.

While a better understanding of future sea level rise is clearly very important, my reason for raising this now is to argue that a much better understanding of the stability and possible trends in atmospheric chemistry can be even more important. Evidence coming from paleoclimatic studies has shown that the Earth can have abrupt changes involving a wide range of interconnected biogeochemical and physical processes, but the extent to which past changes have been related to structural changes in atmospheric chemistry is not yet clear. Furthermore, the increasing emission of new chemical species into the atmosphere means that its composition is already significantly different from what it has been at any time in the past.

Much of our understanding of atmospheric chemistry has come from research on the greenhouse gases that drive climate change, and the need to quantify their sources and removal rates. In particular, this applies to atmospheric oxidation, the basis for which has only been understood for the last forty years and which is still open to significant questions about its trends and even its stability.

Climate change scientists now expect that the environmental changes that will occur over this century, and beyond, may well cross thresholds and enter into some new states for biological and physical systems. If this were to become the case for atmospheric chemistry as well, it opens up major reasons for concern, and recent research on some trace gas species suggests that global average oxidation rates are varying and that there have also been some sudden temporary changes occurring over large regions.

To set the context for atmospheric chemistry being a key factor when considering the implications of global change, the following section provides a short summary of the history that lies behind this field. It covers what have been two major *surprises* for scientists, both of which have meant that atmospheric changes were more serious than originally expected. This is followed by a section describing the new way for measuring atmospheric oxidation rates developed in New Zealand that has now shown evidence for some significant variations. Then I link this to a comparison of the different processes that remove greenhouse gases from the atmosphere and show why atmospheric chemistry is the most important of these. My final comments raise the potential for changes in atmospheric chemistry that are being driven by human activities to create a divergence between air quality in the Northern and Southern Hemispheres. This shows that, ironically, the predominance of emissions in the Northern Hemisphere could possibly lead to worse implications for the Southern Hemisphere.

A Short History of Atmospheric Chemistry

Understanding the greenhouse effect, which determines the Earth's surface temperature, resulted from research that identified CO_2 as a trace gas which, along with water vapour, absorbed outgoing infrared radiation.[3] By the end of the 19th century, Svante Arrhenius had estimated that a global warming of about 4 °C would arise from a doubling of atmospheric CO_2 concentrations.[4] However, he did not expect that to occur for thousands of years, probably because he won the 1903 Nobel Prize in chemistry for his work on electrolytic dissociation that was closely related to the solubility of gases like CO_2. So, initially, there was a general view that the CO_2 being emitted into the atmosphere by combustion of fossil fuels, was being taken up predominantly in the oceans.

Fifty years later, scientists studying ocean chemistry realised that carbonate in sea water is subject to a strong buffering process, which prevents much of the CO_2 that was being added to the atmosphere from being absorbed into the oceans.[5] At the same time, some early developments of the new radiocarbon dating technique were discovering that the carbon in the atmosphere was getting *older* to an extent that could only be explained by fossil fuel CO_2 accumulating in the atmosphere. NZ's Athol Rafter played a lead role in this, and it was quickly followed by Dave Keeling in San Diego developing new methods for accurately tracking the changes in atmospheric CO_2 concentrations.[6]

The initial use of radiocarbon (^{14}C) as a way of distinguishing between natural fluxes of CO_2 and fossil fuel emissions quickly became pre-empted by the development of nuclear weapons testing in the late 1950s. That led to a doubling of the total amount of ^{14}C in the atmosphere in the early 1960s followed by a slow decrease as the atmospheric CO_2 was steadily exchanged with the biosphere and oceans.[7] However, the growing use of radiocarbon dating to determine the age of wood samples from the past also led to more focus on the natural source of ^{14}C, which is due to the effects of cosmic rays penetrating into the stratosphere and upper troposphere.

It was discovered that most of the ^{14}C atoms produced by cosmic rays very rapidly become carbon monoxide (^{14}CO) due to atomic collisions, and are then oxidised again to form $^{14}CO_2$ much more slowly over several months.[8] This means that the natural source of ^{14}CO produces a tracer for the atmospheric oxidation rate that is not directly affected by nuclear weapons testing. The use of this tracer for atmospheric chemistry is taken up in the next section, but a broader picture has to be covered first.

Understanding the atmospheric chemistry for CO came a few years later. Bernard Weinstock, who was on the scientific research staff of the Ford Motor company, produced the first quantitative budget for the production and removal of CO and this was complemented by some more detailed analyses of its sources.[9] But these studies of CO led to questions about both its lifetime and the nature of atmospheric oxidation processes.

A fundamental step forward was to recognise that oxidation in the atmosphere was driven, not by oxygen (O_2) or ozone (O_3) directly, but by a very short lived by-product of photochemistry, the hydroxyl radical (•OH).[10] This growing recognition of the importance of atmospheric chemistry was also leading to more detailed studies of methane (CH_4), which was discovered as an atmospheric trace gas in 1948, but for which the first detailed coverage of its sources and removal processes did not occur until the early 1970s.[11] While CH_4 was initially studied in relation to atmospheric chemistry, it was then realised that the increases in its atmospheric concentrations were causing the second largest contribution to changes in the greenhouse effect.[12]

Further major advances in this area came from the development of techniques to extract air that had been trapped as bubbles in Antarctic and Greenland ice cores thousands of years ago, and to then measure its chemical composition accurately. This showed that atmospheric CH_4 concentrations had more than doubled when going from the ice ages to the warmer interglacial periods.[13] But its concentration had now become more than twice as large again than it had been in those previous warm periods between the ice ages. So the completely new composition of our atmosphere has become recognised in stages.

In parallel with these rapid developments in understanding of atmospheric CO and CH_4, there was also recognition that the release of chlorofluorocarbons (CFCs) from several sources was making significant changes to atmospheric chemistry in the stratosphere. A short paper by Molina and Rowland in 1974 was based on laboratory analysis and not on direct measurements in the atmosphere; nevertheless its abstract clearly stated that *Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms, and leads to the destruction of atmospheric ozone*.[14] Once again, this became recognised as yet another significant contribution to the increasing greenhouse effect and climate change.[15] These rapid developments also involved Paul Crutzen who had unravelled links between CFC chemistry and the nitrogen oxides and, with Molina and Rowland, shared the 1995 Nobel Prize in chemistry, the first time that prize had been awarded for work on environmental chemistry.

Thomas Midgely, who developed the efficient techniques for commercial production of CFCs, had promoted the value of these synthetic and new compounds in the 1920s on the basis that they were not toxic in the way that all the other alternative refrigerants were. The discovery, fifty years later, that their effects on stratospheric ozone could lead to an increase in skin cancer and eye cataracts showed that the effects of changes in the chemistry of our environment can be both subtle and significant, and are something that has to be considered more carefully.

Rapid developments in atmospheric chemistry during the 1970s led to the construction of detailed models aimed at quantifying the chemical interactions between many of the key species.[16] It led to recognition also of major structural differences in stratospheric and tropospheric chemistry.[17] But a key question was still how to determine the oxidation rates that were predominantly due to •OH, which has an average lifetime of only about one second. Furthermore, because this highly reactive radical is produced by solar ultraviolet (UV) radiation, and then reacts with a wide range of species very quickly, its atmospheric concentration fluctuates dramatically from day to night or even when clouds block the incoming UV radiation.

Quantifying the atmospheric oxidation rates, and testing computer models that simulate the underlying processes, has led to a growing reliance on the use of diagnostic species. In this context a one-page paper by James Lovelock developed the approach of using 1,1,1-trichlorethane (also referred to as methyl chloroform - MCF) as an indicator because it was realised that its sources were all anthropogenic and its removal was predominantly due to •OH.[18] This has led to a carefully planned measurement and analysis strategy that has been very productive in quantifying oxidation rates.

By 1979, there was enough information from MCF measurements to produce new estimates of the concentrations of •OH radicals based on measurements.[19] This immediately challenged the atmospheric chemistry modelling of that time, which had estimated much larger oxidation rates. It opened up also a new question because the tropospheric oxidation rate appeared to be significantly larger in the northern hemisphere than in the southern hemisphere. Was that right? Was it due to the higher levels of many anthropogenic trace gases that had been emitted primarily in the northern hemisphere? Or was it due to natural causes? It was clear that there were still major questions about the structure of atmospheric chemistry to be answered.

The need to dig deeper led to development of global networks that measure a range of trace gases in more detail. Ron Prinn, who did his MSc in chemistry at Auckland University and then moved to the Massachusetts Institute of Technology, had started by investigating the chemistry of atmospheres on other planets, but became heavily involved in the development of atmospheric chemistry models for this planet. He developed, and ran, a global atmospheric monitoring network that is still a major source of information on the continuing changes in atmospheric chemistry.[20]

Over the last thirty years, many research groups have contributed to a consolidation of our understanding of atmospheric chemistry following the rapid developments of the 1970s. A simple summary of current understanding of the dominant processes controlling •OH is shown in Fig. 1. There have been several independent estimates of the average atmospheric concentration of •OH and a general agreement that this is about 10^6 molecules/mL, although strong seasonal and diurnal cycles modulate this average value considerably. Atmospheric chemistry models have been constructed that are consistent with much of the available data and also with some direct estimates of •OH concentration, but there are still major questions about how these concentrations may change over time.[21]

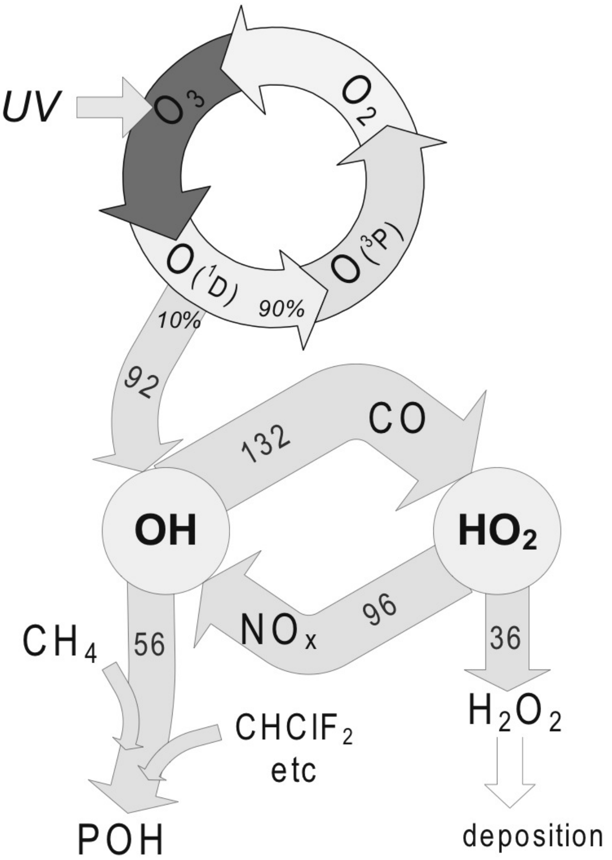

Fig. 1. Representation of •OH chemistry in clean air with values taken from ref. 22. Absorption of UV by O_3 is the initial driver with about 10% of activated oxygen species diverted to •OH through interactions with H_2O; •OH and HO_2 control most of the removal of other species by atmospheric chemistry; POH denotes *partially oxidized hydrocarbons* and the values given within the arrows are in units of Tmol/yr.

An excellent and broad review of our present understanding of •OH has summarised the evidence which shows that, in recent decades, its global average concentration does not appear to have changed substantially, but it was pointed out that this is remarkable given the large increase in CH_4, CO and other trace gases that react with •OH.[23] Lelieveld *et al*. concluded that there had been a balance between significant increases in •OH concentrations over land and smaller decreases over the more extensive oceans, resulting in a net global balance between two types of change driving •OH in opposite directions. But this raises the question as to whether one of these two counteracting drivers may reach a limit leading to significant subsequent changes in atmospheric oxidation rates.

While detailed understanding of atmospheric chemistry clearly has clearly progressed very much in the last thirty years, I want to end this section with a note of caution. In 1985, three scientists from the British Antarctic Survey published the paper that revealed their discovery of the Antarctic Ozone hole.[24] The first two sentences in the abstract of this paper set out the sharp contrast between what was coming from the current detailed models of the stratospheric chemistry for ozone depletion, versus the new observations of dramatic and much larger changes that were being seen over the Antarctic. The observed changes had been so unexpected and so large that some US scientists who had also been making measurements of stratospheric ozone in the Antarctic had assumed that the very anomalous values starting to appear in the month of October were just an instrumental malfunction. They were not.

The 1995 Nobel Prize in chemistry was awarded for major advances in our understanding of stratospheric chemistry, but the range of processes that were involved had taken some time to be identified. As when Svante Arrhenius had first studied the implications of CO_2 increasing in the atmosphere, a growing understanding of environmental chemistry had again revealed that the changes could occur much more quickly than was initially expected, even when the initial research had been carried out by some of the world's best scientists.

New Issues with Atmospheric Oxidation Rates

As noted above, it was recognised in the early 1960s that production of ^{14}C in the atmosphere led to the formation of ^{14}CO which was then oxidised by •OH to form $^{14}CO_2$ over some months. This led to a growing interest in measuring ^{14}CO directly but, given that the atmospheric concentration of CO in clean air is less than 100 ppb and the fraction of carbon in the form of ^{14}C is of the order of 10^{-11}, the fraction of ^{14}CO molecules in the atmosphere is around 10^{-18}, or just 10 molecules/mL of air at standard pressure. This is about 100,000 times smaller than the concentration of •OH which is known to be very difficult to measure. However, there are two reasons why accurate measurements of ^{14}CO are possible. The first is that this atmospheric species can be preserved for a long time in large air samples that are collected and then held in high quality containers. The second is that radiocarbon dating was already being used to measure $^{14}C/^{12}C$ ratios of about 10^{-12}. The difficulties, however, were the need to collect enough atmospheric CO in a large air sample and then separate it from the CO_2 and CH_4, which both have much higher concentrations and quite different $^{14}C/^{12}C$ ratios. This challenging measurement was first made in the late 1970s by Andreas Volz who was able to establish both an initial global average concentration for ^{14}CO and also identify a strong seasonal cycle in the mid-latitudes, expected because of the seasonal cycle in •OH concentrations.[25] However, Volz used a traditional carbon dating technique so this was an extremely difficult measurement to make and its use did not continue.

During the 1980s there was a growing development of accelerator mass spectrometry as a method to provide new isotopic information for atmospheric chemistry on very small samples and much of this started up in New Zealand. In DSIR, Dave Lowe led the development of these new measurements of $^{14}C/^{12}C$ in trace gases and produced the first clear observational estimates of how much of the CH_4 that was accumulating in the atmosphere was due to fossil fuel sources.[26] Carl Brenninkmeijer then moved on to the issue of measuring ^{14}CO by using closely related techniques and developing ways of handling the gas with much lower atmospheric concentrations.[27] These measurements have continued in NZ for over twenty years and were extended into Scott Base, Antarctica, for much of that time. A wider range of measurements became available through aircraft sample collection, developed by John Mak, and the techniques became extended into the Northern Hemisphere as other groups adopted similar approaches.[28] This also led to interpretation of the data using models of atmospheric chemistry.[29]

Continued analysis of ^{14}CO measurements has to take account of an eleven year solar cycle that strongly modulates the production rate of ^{14}C by cosmic rays. After we had data extending beyond one solar cycle, it became possible to compare periods when the production rates had been very similar and to ensure that this cycle in production could be separated from detecting any trend in the rate of removal by •OH.[30] But when this was done it revealed some new features. Thus, Fig. 2 shows the residual in ^{14}CO concentration after taking account of the changes in ^{14}C production rate together with the annual cycle in atmospheric oxidation rate, which explain most of the variations in concentration.[30,31] There is some spread in these results, but there are also patterns of consistency between the two locations, which are about 4,000 km apart. Because there are different delays between sample collection at the two sites and the subsequent laboratory measurement, the similar patterns of behaviour at the two sites excludes variations that might be caused by some systematic laboratory problems for what is a very challenging measurement. Planning for our ^{14}CO measurement programme in New Zealand put a high priority on doing measurements frequently because this is a short-lived tracer that can respond rapidly to changes in atmospheric transport or chemistry. Monitoring of the longer-lived species like MCF can only show much slower responses to changes in •OH and averaged over a much wider area.

The ^{14}CO tracer for atmospheric oxidation shows two anomalous events in our thirteen year record. Marker A in Fig. 2 shows the time of the Mt. Pinatubo eruption in June 1991, which is known to have caused significant changes in atmospheric composition in both the stratosphere and troposphere. Marker B shows an abrupt increase in ^{14}CO that followed soon afterwards and then died away more slowly. This is consistent with some other analyses of changes in atmospheric composition following the Pinatubo eruption, but the ^{14}CO data indicate that there was a reduction in atmospheric oxidation rates by up to 20% over a wide area. The ^{14}CO that is being measured has come down from the upper troposphere, rather than the equatorial region where Mt. Pinatubo is located. So the observed change is being driven by a reduction in •OH in the New Zealand region caused by the transport of trace gases that leads to a delay between the eruption and this observed effect. Similarly, marker C shows the period in 1997 when major and extensive fires occurred in Indonesia. Marker D then indicates the subsequent period when a consequent reduction in oxidation rates of up to 20% occurred again and took more than a year to recover. The ^{14}CO data shown here have been corrected for simultaneous increases in the CO concentration and so this represents a change in the removal rate for the cosmogenically produced tracer.

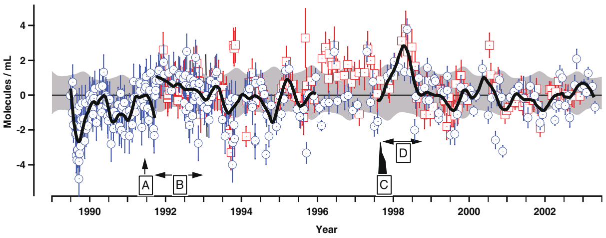

Fig. 2. Blue and red data points are the anomaly in ^{14}CO concentration (molecules/mL) at Baring Head, NZ, and Scott Base, Antarctica, over the period 1989 to 2003, after taking account of expected variations in ^{14}C production due to changes in the solar cycle as well as the seasonal cycle in removal rate by •OH – see refs 30 and 31; the black line is a smooth curve during the periods when there was no significant difference between the two sites and the grey band shows the magnitude of variations that would be expected for a 10% change in •OH; the events labelled A-D are described in the text.

Other studies have looked at specific aspects of the change in atmospheric composition that are linked to these events but, while some model-based estimates show changes in oxidation rates, these have not been large enough to explain the observed ^{14}CO changes.[32] A possible reason for this is that the full range of processes that control •OH may not have been included in those model calculations.

There is another implication of the data shown in Fig. 2, which is that the 1991 event may have led to a step up in ^{14}CO concentration, implying a step down in atmospheric oxidation rates, after which there was never a complete recovery. This has to be treated with caution though, because it was only after late 1991 that we had measurements taking place in both NZ and Antarctica and from then on it was the close agreement between these sites that enabled more reliable identification of systematic changes in atmospheric chemistry over a wide region.

The results coming from ^{14}CO measurements in both hemispheres have been analysed using global models that cover atmospheric oxidation rates as well as transport. A key issue in this respect is the need to explain a smaller difference in ^{14}CO between NZ and Antarctica than exists across the same latitude range in the Northern Hemisphere: some initial analyses had expected more symmetry between the two hemispheres.[33] A more recent analysis has suggested this can be explained by modifying the spatial distribution of ^{14}C production, which is an area of continuing uncertainty.[34] However, this ability to adjust models to explain observations shows that there are still some significant uncertainties, rather than clear explanations. In my view, there is still a major question as to whether different ^{14}CO distributions in the two hemispheres reflect some differences in atmospheric chemistry.

A result that can be related to this has come from extensive measurements of the ^{13}C/^{12}C ratio for CH_4 in NZ and the South Pacific region. Analyses of the data combining the effects of atmospheric chemistry and transport have shown growing evidence that some removal of CH_4 is due to reaction with chlorine.[35] Recently, this proposed explanation of the CH_4 isotopic data in the Pacific region has become reflected in new northern hemisphere studies which also suggest a larger role for chlorine in tropospheric chemistry in the marine environment than had been expected.[36]

Atmospheric Oxidation is the Major Control on Climate Change

While there are still significant questions about atmospheric chemistry, I would like to now summarise the importance of this, and particularly of •OH, from a broader environmental perspective. This will consider the implications for climate change, but it should also be recognised that changes in atmospheric chemistry can have a much wider relevance.

Much of our understanding of changes in greenhouse gases is often expressed simply as the net change in concentration that is occurring in a year. However, a proper comparison of the different gases has to consider the full range of natural processes that are removing them from the atmosphere and the ways in which these processes may change in the future. For this reason, it is important to consider the gross fluxes into and out of the atmosphere rather than just the net result. The flux into the atmosphere is dominated by anthropogenic activity, and the flux out is the critical aspect of natural responses mitigating that activity.

In the case of the global carbon cycle, about 28% of atmospheric CO_2 undergoes exchange with other reservoirs in the biosphere and oceans each year.[37] So, while the addition of a little more than 1% of atmospheric CO_2 each year due to the use of fossil fuels is a driver for climate change, it is also very necessary to understand how the global cycle will respond in future. Similarly, for the other greenhouse gases, it is important to consider the natural removal processes and their potential for future changes. In the case of CH_4, the net annual changes in concentration are very small, but this is because the emissions are very close to the removal rate of about 10% each year. As the greenhouse effect is more sensitive to changes in CH_4 than in CO_2, this means that the removal process for CH_4 is playing a larger role in limiting climate change than the carbon cycle.

This type of comparison of the removal processes that are currently compensating for emissions was put together recently by expressing the removal rates of all the different gases in terms of the consequent rate of reduction in radiative forcing.[38] This also leads to a grouping of the drivers of climate change according to the natural processes that are controlling them and this is shown in Fig. 3. The key factor emerging from this comparison is that atmospheric oxidation by •OH is playing a bigger role in reducing the forcing of climate change than the global carbon cycle and that this has been the case for the last fifty years.

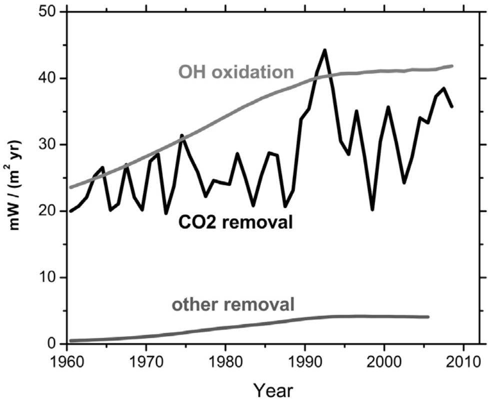

Fig. 3. Radiative forcing removal rates that show the nine greenhouse gases with the largest contributions grouped according to the removal process as follows: oxidation by •OH, removal of CO_2 by vegetation and oceans, and all other removal processes – see ref 38.

The slight upturn in the role of •OH in the last three years is partly due to an increase in atmospheric CH_4 concentration, for reasons that are still not fully understood, and partly because of a continuing increase in the fluorohydrocarbon HCFC-22 ($CHClF_2$). This also shows that when the role of different greenhouse gases is considered in the context of a growing reliance on natural removal processes, then HCFC-22 is now the third most important gas, not N_2O as it seems if one only looks at the net changes rather than the actual processes.

The importance of •OH (and the closely associated atmospheric chemistry) in controlling climate change clearly needs a much more thorough level of understanding. Current scientific literature generally shows that the potential increases in concentrations of many trace gas species are expected to decrease •OH but, in contrast to that, higher levels of tropospheric ozone and of atmospheric water vapour due to warming are both expected to increase •OH.[39] There is also a need to consider wider ranging chains of interactions - a recent study has linked the increase in stratospheric N_2O to a reduction in ozone that increases UV radiation into the troposphere and so the concentration of •OH.[40]

As noted earlier, the amount of information on past trends in •OH is very limited, but there are several reasons for expecting it to have decreased since the 18th century. That was reinforced recently by analysis of sulfate in Antarctic ice cores and shows evidence for significant increases in the concentrations of O_3 and H_2O_2 over the last 150 years, which implies that there will also have been a reduction in •OH.[41]

Much of what has been covered here is consistent with the summary provided by Lelieveld *et al*., which suggested an increasing difference between •OH concentrations over land and ocean due to systematic differences in the changes that are occurring there.[23] As shown in Fig. 1, increases in NO_x that can be linked to fuel combustion and agricultural emissions, tend to increase the production of •OH. However, NO_x is a very short-lived species and so its influence on atmospheric chemistry stays close to its sources over land.

Thinking About the Future

The fact that •OH is predominant in mitigating anthropogenic climate change, shows the seriousness of being able to project how it is likely evolve in the future. So far, our history shows that we have learned about some of the critical features in atmospheric chemistry after major changes have started to take place. We are modifying a complex non-linear system that we still do not understand in detail, and there may be a potential for abrupt changes if some trigger points are reached.

While it appears that counteracting drivers of change in •OH have been globally balanced over recent decades, the key issue is whether this may change in future and whether our current knowledge is adequate for determining that. As noted above, there are reasons for expecting the drivers for change in •OH to be different over land and ocean. However, rapid mixing within the troposphere will tend to merge these two trends within each hemisphere, so it becomes more an issue of differences between the two hemispheres.

The predominant emissions that are leading to changes in atmospheric chemistry are located in the Northern Hemisphere and this means that the Southern Hemisphere is more likely to show effects that are dominated by the longer-lived species. CO lasts for 2–3 months in the troposphere, so its effect on depleting •OH can be expected to propagate much more widely than the counteracting effect of NO_x. That could lead to CO being a more significant factor in the Southern Hemisphere. However, because the CO lifetime is short compared to the interhemispheric mixing time of about one year, its flux from the Northern to Southern Hemispheres is small. A bigger issue could emerge from the very different ratio of land to ocean areas in the two hemispheres and this again suggests that CO depletion of •OH is more likely to become dominant in the Southern Hemisphere.

To set a broader context for these issues, one of the major advances in understanding global change was a paper by Roger Revelle and Hans Suess in 1957 that built on earlier work done in New Zealand by Athol Rafter.[5] At that stage, the potential CO_2 changes that were being recognised were described as *a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future*. Unfortunately, I now have to disagree – we could reproduce this type of *experiment* with anthropogenic changes in atmospheric chemistry.

Understanding future stability is not easy in the context of atmospheric chemistry, and in this context I want to cite Nobel Prize Laureate, Sherwood Rowland who, soon after being awarded his 1995 prize, was invited to give an overview lecture in Brisbane at an international conference on environmental science. He then had a session with a small group of us in which he summarised what he saw as the serious issues in atmospheric chemistry. To my surprise, he spent much of his time talking about the importance of our measurements of ^{14}CO in NZ because these could unravel much more information about changes in atmospheric oxidation rates. But when I then asked Rowland if we could identify just a few key components of atmospheric chemistry so as to focus our limited research funding, he came back firmly saying that we had to treat this as an area where very minor trace species could play major roles in our atmosphere and that we must not assume that we knew what those all were.

There is a wide range of new species being added to the atmosphere and this short summary has not covered any of the growing recognition that aerosol chemistry is another key factor in all of this as well. It has to be recognised that chemistry plays a major role in our atmosphere and that it is now in a completely new state that has never existed before. The complexity of atmospheric chemistry, and the number of factors that it is already responding to, means that we should neither take it for granted nor assume that we can just extrapolate past trends. Instead, we now have to dig much deeper and develop a clear basis for understanding its resilience to global change.

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Chemistry in New Zealand *April 2011*

Pacifichem 2010: Excerpts from a Student's Diary

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Note from the 2010 NZIC President

As one of the seven sponsoring societies of Pacifichem, the NZIC holds a privileged position among the many chemical societies represented at the Congress. The NZIC has a permanent representative on the organizing committee (currently Prof Rob Smith - University of Otago) and the NZIC President is invited to attend the Opening Ceremony in an official capacity and then a dinner on the final night of the conference with the organizing committee and the Presidents and Chief Executives of the other six sponsoring societies (ACS, CIC, JCS, CCS, KCS, RACI). At Pacifichem 2010, the NZIC President also attended a meeting of the Asian Chemical Editorial Society (ACES), the governing body of Chemistry - An Asian Journal, of which NZIC became a member in 2008,the first time an NZIC representative had been able to attend an ACES meeting.

Despite the fact that NZIC delegates are heavily diluted by their counterparts from the ACS, CIC and especially the JCS, the NZIC has approximately proportional representation across a wide range of fields from relativistic computational chemistry to organic synthesis and environmental chemistry.

Mark Waterland
President in attendance

Introduction

The International Chemical Congress of Pacific Basin Societies, *Pacifichem*, is one of the largest chemistry conferences in the world. Composed of the chemical societies of the Pacific Basin and held every five years in Honolulu, the Congress aims to promote scientific exchange for a healthy and sustainable future. During December 15-20 last, Pacifichem 2010 hosted 13 areas of chemistry, 239 symposia, 12,844 technical presentations and 12,751 scientists.

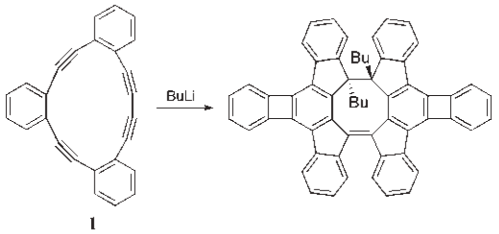
As one of the largest chemistry conferences in the world, a group of four PhD and MSc students from Victoria University, out of the 76 Kiwi attendees, decided this might be a good one to cut our teeth on. Due to flight availability, we *had* to arrive four days early and have a short holiday in Honolulu. Having surveyed the view from Diamond Head crater, swam with the sea life amongst the Hanauma Bay coral, visited Chinatown and lounged around at Waikiki Beach, and whilst drinking from coconuts and sipping Mai Tais, we decided it was a hard life being a student. We learned a few lessons during our time there: the sugar coating of breakfast cereal can be removed by pre-washing with water; mechanically-separated turkey franks are surprisingly good; and the art of *FreeCon* - walking close to the open doors of shops (Gucci, Chanel and Hugo Boss in particular) to get free waves of air-conditioning. All this aside, we were there for a conference.

Early Days

Given my diverse interests, I attended a wide range of talks. The first was by Prof. Tehshik Yoon (University of Wisconsin), who is investigating using visible light to photocatalyze organic reactions by use of a $Ru(bpy)_3^{2+}$ catalyst. Prof. Juan Scaiano (University of Ottawa) presented related work, but utilizing surface plasmon fields of gold nanoparticles instead. In the presence of a monomer precursor, cross-linked acrylic shells form around the nanoparticles and from the diameter the field effect was estimated at 8-10 nm. Meanwhile, Prof. Vaidhyanathan Ramamurthy (University of Miami) presented work on using weak non-covalent forces to control photochemical reactions. This included encapsulating reagents in cavities such as provided by γ-cyclodextrin, and crystallization with hydrogen-bonding species such as thiourea.

The Pacifichem Congress plenary was delivered by Prof. Paul Corkum (University of Ottawa), entitled *Catching Electrons with Light*. Whereas the molecular orbitals we all know are 90% *probability surfaces*, Corkum is now using attosecond laser pulses to help create images of *actual* electrons orbiting molecules.[1] Furthermore, his more recent work involves following chemical reactions as they occur.[2] I cannot do the man or his work justice in trying to present the science here, so I encourage you to read the cited papers.

Prof. James Wuest (University of Montreal) has taken highly-crystalline hexaphenylbenzene-based compounds and found ways to structurally inhibit crystal formation, *as all good crystal engineers should be able to*, he added. Prof. Clémence Corminboeuf (Ecole Polytechnique Fédérale de Lausanne), amongst her interest towards a more physical understanding of chemical concepts, presented work assessing π-conjugation effects by computationally comparing discrete resonance structures with their conjugated-counterparts. This work could have applications in the field of Möbius aromaticity, where there is much conjecture over aromatic parameters. In the same symposium, entitled *Designed pi-Electronic Systems* Prof. Yoshito Tobe (Osaka University) showed serendipity is always a force in chemistry with the dehydrobenzo[14]annulene (**1**) undergoing unexpected dimerization (Scheme 1). As to the mechanism: I don't know, he said with a laugh.



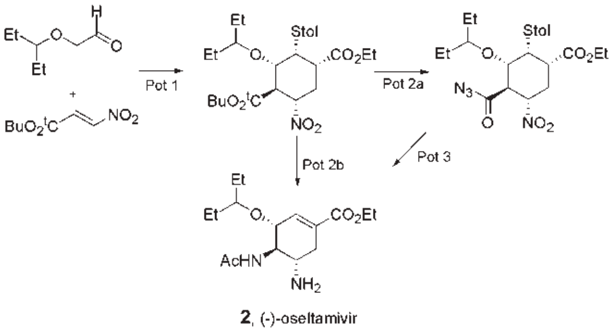
Scheme 1. Tobe's unexpected dimerization

Masters of Synthesis

One-Pot Synthesis - Yujiro Hayashi

Tamiflu, the phosphate salt of oseltamivir (**2**), is an antiviral drug that can slow the spread of influenza virus and was hurriedly stockpiled by governments during the *bird* and *swine flu* pandemics. Commercial production was originally based on shikimic acid, a biosynthetic intermediate of low natural abundance and of low extraction yield, leading to supply problems. A short, high-yielding, inexpensive synthesis was therefore required. Alternative total syntheses were put forth by many chemists, each surpassing one another in yields and steps.[3] The record was last held by Barry Trost and Liang-Deng Nie, with eight-step syntheses of 30%[4] and 47%[5] overall yields, respectively, until Prof. Yujiro Hayashi came on the scene with a three-pot, 57% yield total synthesis.

Utilizing a mixture of Michael, retro-Michael and Horner-Wardsworth-Emmons reactions, as well as functional group modifications and a Curtius rearrangement, and relying upon evaporation of excess reagents and solvents, (-)-oseltamivir could be obtained from three-pots without the need to exclude water or air and need for but one column chromatography (Pots 1, 2a and 3, Scheme 2).[6] Having presented this during his talk, Prof. Hayashi then asked the question: *Why not two-pot?* By modifying reagent choice to allow solvent compatibility, a two-pot synthesis of oseltamivir can be completed with a 60% yield and a single column chromatography (Pot 1 and 2b, Scheme 2). Prof. Hayashi then asked another interesting question: *Why not no columns?* Replacing the single column with two acid-base workups, Prof. Hayashi has also now synthesized oseltamivir in three pots with a 60% yield and *column-free*. This is the sort of work that synthetic chemists talk about in their sleep. On a personal note, I sadly mean that literally.

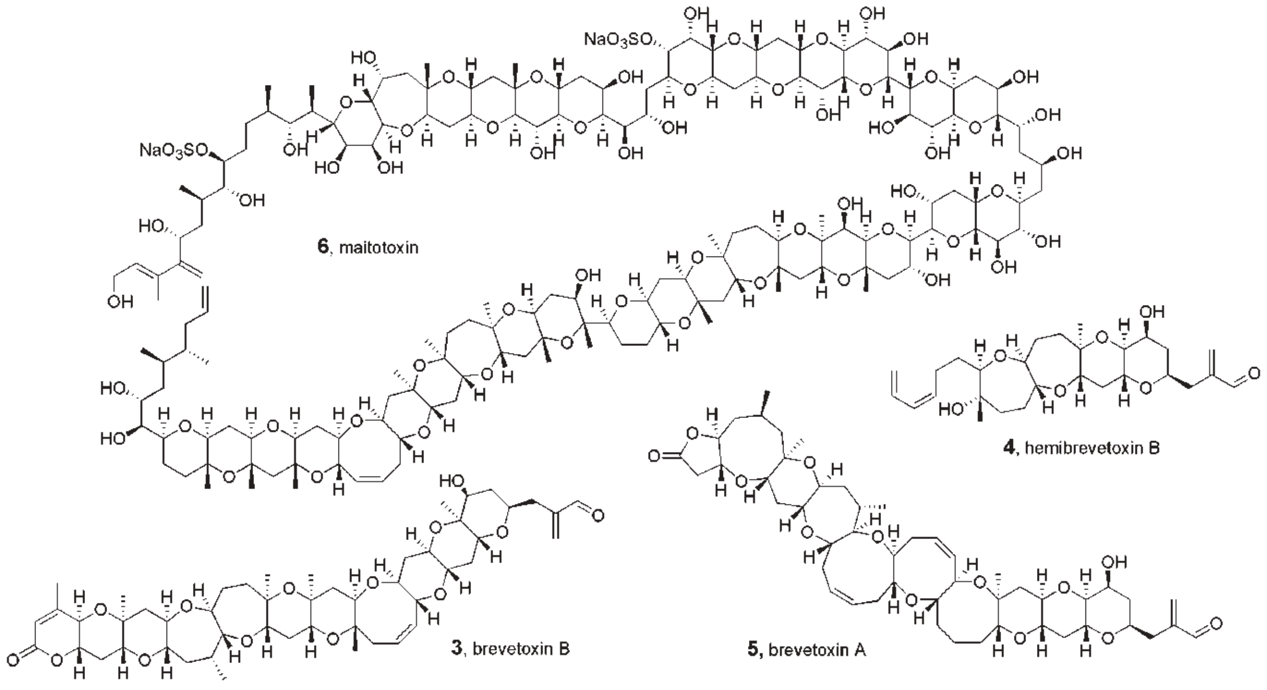


Scheme 2. Hayashi's syntheses of oseltamivir (2).

Marine Polyether Biotoxins - K. C. Nicolaou

You know a superstar is talking when you arrive an hour early and there is already standing-room only. Prof. K. C. Nicolaou (Scripps Institute) began his talk on marine polyether biotoxins by highlighting his progressive baldness over his career. He made many comparisons to his friend, Masakatsu Shibasaki, who was sitting on the floor after vacating his seat for a blonde, female student standing nearby (some things never change). Nicolaou then presented his vision of synthetic chemistry: *We do it to advance the art of total synthesis for our own sake and for the excitement it provides… Musical notes combine to create a melody. Similarly, chemical reaction notes combine to create natural product melodies.*

This study began on a day in November 1981, when he came across a paper reporting a new marine polyether called brevetoxin B (**3**), a highly-potent biotoxin. Having seen its molecular complexity, immediately he locked himself in his office and tried to work out how to make it. He emerged two hours later *with no clue*. The epoxide chemistry needed to synthesize the molecule simply



6, maitotoxin

4, hemibrevetoxin B

3, brevetoxin B

5, brevetoxin A

did not exist. So he developed some. Eight new synthetic methods and twelve years later, the total synthesis of brevetoxin B was complete with its report subtitled *A Twelve-Year Odyssey in Organic Synthesis*, lending credence to the monumentality of the feat.[7] Hemibrevetoxin B (**4**) also was synthesized along the way,[8] followed by brevetoxin A (**5**).[9] This left the trifling matter of synthesizing a related highly-potent marine polyether, called maitotoxin (**6**).

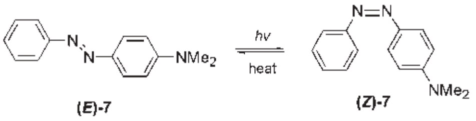
When I first saw this compound as an undergraduate student, I laughed because I knew no-one would ever synthesize it. Polyether **6** is the largest non-biopolymeric secondary metabolite ever isolated, with a molecular mass of 3422 g/mol; it is also the most complex, with 32 rings and 99 elements of stereochemistry. Needless to say, when Nicolaou first mentioned the name maitotoxin in his talk, I nearly choked. Rather than diving into the total synthesis, as I expected, he presented molecular calculations on a section of the molecule to settle a disagreement over the stereochemistry at two centers[10] - and here it is pertinent to point out that part of a review article was dedicated simply to summarizing structural elucidation attempts.[11] But, having obtained an answer, he said *these are just calculations*, so he synthesized the relevant fragment of the molecule to support his finding.[12] Having done this, he decided to synthesize another fragment[13] or two.[14] Following years of research and the development of further novel reactions, he now stands four rings, and some funding, short of the total synthesis of **6**, *that is, if one desired to make it*, he added whilst sipping some water. Being the young, impressionable youth that I am, I shall never forget that talk. An interesting reflection on Nicolaou's career is available.[15]

The Mid-Congress Blur

Prof. Ei-ichi Negishi (Purdue University), the 2010 Chemistry Nobel Laureate, mentioned off-hand during his talk that, having just returned from Stockholm, he had his Nobel medal in his wallet. There was a subsequent 10-minute delay in his talk whilst members of the audience got photos of him with said medal. Prof. Robert Grubbs (CIT), of catalyst and 2005 Nobel-prize fame, could be seen between the heads of people crowding out the door at his *standing room only* talk, as was Prof. Eric Jacobsen (Harvard University), famous for the Jacobsen epoxidation.

Since my school days, I have been fascinated with hydrogen as a clean and renewable alternative to fossil fuels. Despite images of former-Governor Arnold Schwarzenegger standing proudly beside his hydrogen-powered Hummer, a remaining hurdle to this technology is the green generation of hydrogen, which is now being solved by splitting water using sunlight. I attended a number of talks directed towards achieving this, using various colloidal metals and ligands to optimize the absorption of light and the redox reactions. Rather than inaccurately present their work here, I direct you to the work of Stefan Bernhand (Carnegie Mellon University), Kazuhiko Maeda (University of Tokyo) and Felix Castellano (Bowling Green State University).

Back at the Hilton, Prof. Hideko Koshima (Ehime University) presented her work on microcrystals that bend upon UV irradiation. Composed of (*E*)-(4-dimethylamino)azobenzene [(*E*)-**7**] they undergo photoisomerization to the *Z*-form [(*Z*)-**7**) upon irradiation. This results in an observable bending of the plate-like microcrystals (Scheme 3). The work of Terunori Fujita (Mitsui Chemicals) was also presented, in which he described the ways found to industrially convert bioethanol into propylene for use in polymer manufacture. Elsewhere, Bernd Ondruschka (University of Jena) extolled the values of sonochemistry, the use of acoustic cavitation - sound wave-generated bubble formation and collapse - to produce chemical and physical changes. When used in biodiesel production, yields increased from 5.5% to 77.3%; one can understand his support.



Scheme 3. Photoisomerization that results in crystal bending.

Emerging Areas of Chemistry

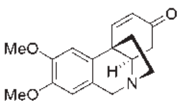
Flow chemistry - Steven Ley

Continuous-flow chemistry is shaping as a new dimension in organic synthesis. The procedure is one where reactions occur in a continuously-flowing stream and involves pumping dissolved reagents through narrow units with different chemical functions that induce chemical transformations.[16]

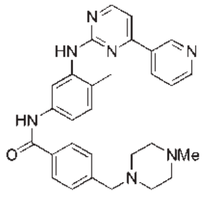
These units can range from columns packed with immobilized reagents or catalysts to microwave and hydrogenation reactors to scavenging cartridges or chromatographic columns. Combining these in a linear sequence can allow the total synthesis of some natural products to be completed in a continuous operation.

This field has largely been pioneered by Prof. Steven Ley at Cambridge University. His flagship synthesis is that of the alkaloid oxomaritidine (**8**)[17] This utilized azide-exchange resins, polymer-supported phosphines, flow hydrogenators and microfluidic reaction chips, amongst others, to give the alkaloid in 40% yield. There was a single product-handling step, namely the highly strenuous act of swapping solvents from THF to DCM. Some of the key units developed by the Ley group are tube-in-tube gas flow reactors, which deliver safe levels of dissolved gasses, and IR & UV sensors that match the delivery concentration of a reagent to the concentration of product flowing through the system, which disperses during passage through the reactors.

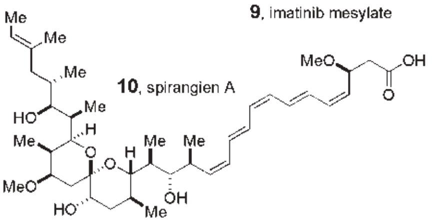
The work has been so successful that drug companies now seek him out to attempt syntheses of their pharmaceuticals. The flow-based synthesis of the anticancer drug imatinib mesylate (**9**) is a prime example.[18] For this, a solvent switch was developed, removing a lower boiling solvent by bubbling through an inert gas. The Ley group is currently targeting the antifungal spirangien A (**10**) in an early example of flow chemistry directly competing with bench-top chemists. Ian Paterson, also of Cambridge, completed the total synthesis of **10** in 2008, in 18 steps and a 2% yield.[19] So far, Ley has completed a 150 g synthesis of a key building block, run by a student's cell phone from a remote location. Given the automation and speed possible with flow chemistry, this certainly appears to be the future of industrial pharmaceutical production. A recent reflection of Ley's natural product work has appeared.[20]



8, oxomaritidine



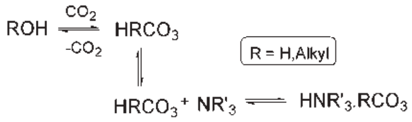
9, imatinib mesylate



10, spirangien A

Switchable Solvents - Philip Jessop

Prof. Philip Jessop (Queen's University) has worked towards developing solvents with properties that can be changed upon command. Organic reactions are usually performed in solution, but product separation is then required. Distillations require volatile solvents and energy, adding antisolvent generates more solvent waste and extraction into another solvent *still* requires separation. A new solution to this is *switching* the solvent from one type to another. Prof. Jessop is developing solvents that change their polarity, reversibly, upon addition or removal of CO_2. The equilibria between carbon dioxide and water or alcohols generate acidic species that protonate nitrogen atoms of the solvent and increase its polarity (Scheme 4). These equilibria can be reversed by bubbling through an inert gas or heating. To date, three sorts of switchable solvents have been investigated.



$$\begin{tikzcd} \mathrm{ROH} \arrow[r, shift left, "\mathrm{CO_2}"] & \mathrm{HRCO_3} \arrow[l, shift left, "-\mathrm{CO_2}"] \arrow[d, shift left] & \boxed{\mathrm{R = H,Alkyl}} \\ & \mathrm{HRCO_3} + \mathrm{NR'_3} \arrow[u, shift left] \arrow[r, shift left] & \mathrm{HNR'_3.RCO_3} \arrow[l, shift left] \end{tikzcd}$$

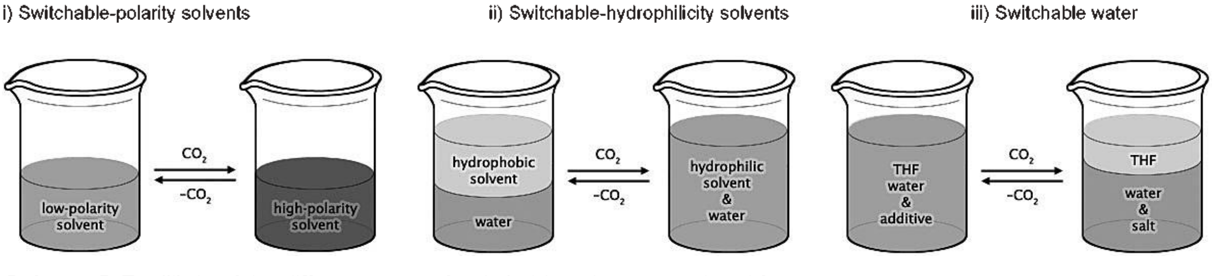
Scheme 4. Equilibria occurring within a switchable solvent.

Switchable-polarity solvents, as their name suggests, change polarity upon addition or removal of CO_2. Typically, these are mixtures of an amidine base and an alcohol that are inherently nonpolar, but form ionic liquids upon addition of CO_2 (Scheme 5i).[21] Switchable-hydrophilicity solvents change their miscibility with water as a result of polarity change (Scheme 5ii).[22] Composed of biphasic mixtures of non-polar amidine and water, upon addition of CO_2 they form a monophasic, high-polarity solvent, which affects the solubility of any solutes originally in the amidine. These two approaches have been used in the extraction of soy bean oil from soy bean flakes.[23] Commercially, the oil is extracted using a hexane solvent (*flammable, high insurance costs, hazards- toxicity, narcoticity… I can't even pronounce the rest of them*), which is then distilled off. Switchable solvents can be used to extract the oil, which, upon addition of carbon dioxide, separates out as a pure compound. After decantation and carbon dioxide removal, the solvents are returned to their original state ready for reuse.

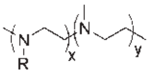
The newest approach involves switchable water – a reversible *salting out* approach. When a homogenous solution of water and an organic solvent, such as THF, with an uncharged diamine additive is exposed to CO_2, the additive becomes charged, raising the ionic strength of the water, and hence immiscibility with the THF (Scheme 5iii).[24] Although salting out approaches have been frowned upon by industry owing to the irreversible generation of large quantities of salty water, this system can be reversed simply by removing carbon dioxide. This could find use in organic synthetic chemistry due to the ability to extract catalyst or product by blowing on the reaction. In addition to use in industrial settings, this area of chemistry also could lead to some interesting advances in the scope of solvent-phase reactions.

Artificial Enzymes - Ronald Breslow

Enzymes are the synthetic chemists of the natural world. They catalyze specific reactions in aqueous environments containing many different species and with complete regio-, chemo- and stereoselectivity. The key to this it their ability to form, through folding and interactions, very specific binding pockets in space that position key catalytic moieties and exclude water and other molecules. Artificial enzymes, therefore, may be able to replicate these activities, but without the concerns of hydrolysis or *death* of the enzyme. Towards this aim, Prof. Ronald Breslow (Columbia University) has been attempting to synthesize artificial enzymes. Using biology as an inspiration (not as a blueprint- *a jumbo jet is not just a scaled up pigeon*),[25] modified polyethylenimines (PEIs, **11**) are used as enzyme surrogates. These polymers self-assemble in water to form micelle-like structures, with water-excluded cores that act as binding domains. These cores promote the hydrophobic binding of substrates and coenzymes, molecular entities that associate with enzymes and contain key functional groups for enzymatic catalysis.



Scheme 5. Equilibria of the different types of switchable solvents; reprinted from: http://www.chem.queensu.ca/people/faculty/jessop/switchable.html with permission from Philip Jessop and Darrell Dean.



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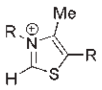

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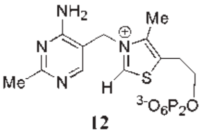

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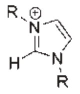
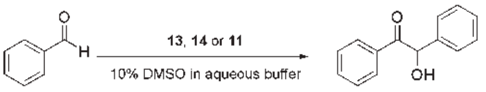


14, R = alkyl

Thiamine diphosphate (**12**) is a coenzyme that, by way of a stable, nucleophilic carbene generated at the C-2 position, can catalyze condensation reactions that generate α-keto alcohols. Thiazolium **13** and imidazolium **14** synthetic equivalents of this, therefore, were trialed in a benzoin condensation (Scheme 6).[26] The presence of **13** or **14** alone can catalyze the benzoin condensation, but in the presence of **11** their alkyl chains promote incorporation into the *enzyme* core, completing the artificial enzyme, and a 3000-fold acceleration in reaction rate is seen. Although the field is still young, designed artificial enzymes with all the synthetic abilities of natural enzymes may one day be achievable. We are now one step closer to taking biochemistry back from the biologists.



Scheme 6. The benzoin condensation

Social Gatherings

The conference was not all work and no play! The evenings rapidly became filled with receptions and functions. The opening ceremony, with traditional Hawaiian dances that felt reminiscent of dances from home, was followed by a large reception on the lawn of the Sheraton Hotel. Another reception was charged with ushering in the International Year of Chemistry, 2011, at the lagoon of the Hilton Hawaiian Village (Yes, the Hilton has its own lagoon - and penguins). In addition, the Law Division of the ACS generously hosted an open-bar reception by the pool of the Hyatt Hotel (I thank the ACS for numerous Mai Tai's). On a more personal level, the symposium on *New Dimensions of Green Sustainable Chemistry* had a small reception for attendees. During this time, we got to chat, over a few beers and many chicken kebabs, with Prof. Chris Strauss, who can be thanked for the existence of microwave organic synthesis. The photograph (see below) was taken towards the end of the reception, and pictures Hemi Cumming, a VUW PhD student, and the author with Chris Strauss, C-J Li, an eminent organic chemist in Canada, Tamim Braish, director of pharmaceutical process discovery at Pfizer, and Shu Kobayashi, of water-compatible Friedel-Crafts-catalyst fame. The symposia-related receptions are a great way to meet people in your area, and I simply wish there were more.

The Final Days

Prof. C.-J. Li (McGill University), in a symposium entitled *C-H functionalization*, presented his group's work towards forming C-C bonds from C-H bonds using cross-dehydrogenative couplings that use cheap catalysts and oxidants. This novel reaction avoids protection-deprotections, whilst allowing catalytic functionalization of C-H bonds and direct C-H/C-H couplings. After an hour-long tour through the reactions they have explored, from using magnetic nanoparticle catalysts to allow catalyst conservation, to site-specific peptide modifications, he summarized by highlighting that they now had examples of creating C-C bonds from all possible combinations of sp, sp^2 or sp^3 C-H-bonded starting materials. After such a relaxed, early-morning talk, it was an awe-inspiring conclusion, and emphasized his position in the Canadian organic synthesis scene.

Jón Njarðarson (University of Arizona) showed that perseverance sometimes is needed in chemistry, by detailing seven different routes he attempted towards the synthesis of the natural product vinigrol. Prof. David Black (University of New South Wales) meanwhile raised the concern that screening for novel reactions should utilize activated models rather than unsubstituted-parent compounds. Finally, as an example of convergent research interests, Prof. Jef DeBradander (Texas Southwestern Medical Centre) was discussing a potential synthetic pathway to the natural product spirastrellolide in one room whilst, minutes before, Prof. Ian Paterson (University of Cambridge) had presented his total synthesis of it just next door.

Symposium Reception. L-R: Hemi Cumming, C.-J. Li, Shu Kobayashi, Tamim Braish, Chris Strauss, Peter Clark. Photo credit - Peter Moore.

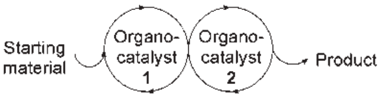
New Approaches in Synthesis

Contemporaneous Dual Catalysis

Dual catalysis involves two catalysts generating two reactive intermediates that couple to produce a new compound. Being catalytic quantities of reactive intermediates, however, these tend to form byproducts with stoichiometric species present instead. By controlling the rate of formation of the intermediates, chemoselectivity can dominate over concentration effects and the desired product can be formed. In what he has termed contemporaneous dual catalysis, Recently, Prof. Barry Trost (Stanford University) has been able to generate a coupled product from intersecting vanadium- and palladium-catalysed cycles, showing dual catalysis can be a feasible approach.

Organocascade Catalysis and Collective Total Synthesis

The final talk I attended certainly did not disappoint. Although metal-catalyzed cascades (where products of one cycle feed into another) exist, Prof. David MacMillan (Princeton University) only recently has *disclosed* the concept of performing these with organocatalysts (Scheme 7).[27] His flagship synthesis of aromadendranediol involves a triple-cascade, in which the product of a cross-metathesis cycle feeds into an iminium cycle which then feeds into an enamine cycle, highlighting the synthetic value of this approach.[28]



Scheme 7. Organocascade catalysis

His second novel approach requires changing the mindset of chemists when synthesizing chemical families. Traditionally, specific methods are devised for each member of a family. What MacMillan instead suggests is collective total synthesis - using a general synthesis to a common intermediate, then diversifying. This has benefits towards creating families for biological testing, but also towards families of natural products. The *Strychnos* family, for example, has over 100 members that have been synthesized to date. In soon to be published work from a common intermediate, he achieved the total synthesis of members of this family, which was more efficient than the existing specific syntheses.

Final Thoughts

Reflecting on Pacifichem 2010 (and a school of fish leaping over my leg on the shore of Hanauma Bay), a few comments come to mind. It was an invaluable opportunity to see and hear research at the forefront of scientific discovery, by the people leading their fields, and I know that I have been inspired to approach my work with renewed vigour and new ideas. The conference fulfilled its aims of facilitating scientific exchange towards a sustainable future, as is clearly visible in the drives towards making chemistry green and with alternative energy technologies. However, these all rely on our current theories of atoms and molecular orbitals being correct. The concept of the atom that we have today has evolved hugely through time, and many theories, subsequently disproven, were at one point held as truth. With so much of organic chemistry reliant on molecular orbital theory, the question is will this one day be disproven too? With the exponential growth in computational chemistry, it may be only a matter of time until *regular irregularities* induce another evolution in chemistry and our understanding of the world. Only time will tell what Pacifichem 2015 will hold in store for us.

Acknowledgements

I acknowledge financial support from the Rotary Club of Terrace End Memorial Education Trust and the Wellington Branch of NZIC for making my attendance at the conference possible. I also thank my travelling companions, Hemi Cumming, Jacqui Barber and Peter Moore, for adding to the interest of the trip.

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In the Year of Chemistry: From Mendeleev to Albert Einstein – The Periodic Table of the Elements and Beyond

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About the Author

Peter Schwerdtfeger is the Director of the Centre for Theoretical Chemistry and Physics at the New Zealand Institute for Advanced Study in Massey University's Albany campus. He is a German and New Zealand citizen, having been born in Stuttgart in 1955 and gaining his education in that city with the University of Stuttgart his *almer mater*. His doctoral advisor was Heinz-Werner Preuss

Initially at the University of Auckland in the late 1980s, where he established a formidable reputation in theoretical chemistry and physics, Peter moved to Massey's Albany campus in its early days where he focuses on virtually all areas of electronic structure theory in chemistry and physics. He was awarded the prestigious Humboldt Prize, by the Alexander von Humboldt Foundation in Bonn (Germany) late last year for his fundamental work in the area theoretical chemistry and is a recipient of the RSNZ Hector Medal.

At 12, Peter was given a chemistry set and proved to be so good at blowing things up that his parents received a stern visit from the Stuttgart police. But his thrill of seeing what happens when one atom meets another is unchanged: *Science*, he says, *is fun*. The titles of his research projects lie in the polysyllabic jungle of *heterogeneous catalytic processes* and *electroweak interactions* but have connections to an extraordinary range of potential future technologies, from methods for finding new Alzheimer drugs to reducing the global warming effect of NZs burping cows, or even – one day – to ways to filter the methane out of gassy coal mines, reducing the chance of tragedies such as the Pike River Coal mine disaster.

Underpinning all of Peter's investigations is the grey area between physics and chemistry. He is expert at running extremely precise computer models of chemical reactions at the level of individual atoms, enlisting not only the quantum equations that describe the weird indeterminacy of the subatomic world, but also Einstein's relativistic equations that describe the weirdness of objects moving at high velocities.

Such high-speed relativistic effects are often disregarded by chemists, because the outermost electrons that cause atoms to cling together move pretty slowly. But, in fact, even small relativistic effects can be significant, and taking them into account has let him solve mysteries that some of us probably hadn't even realised were mysteries.

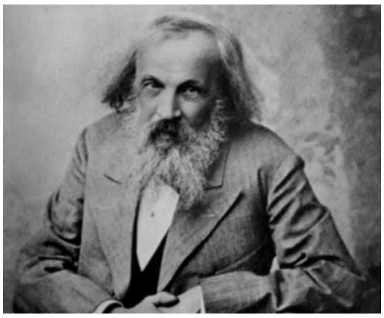
Members may remember that it was Peter and his Auckland team that organized the NZIC's 2006 conference in Rotorua.

For me too, the periodic table was a passion. ... As a boy, I stood in front of the display for hours, thinking how wonderful it was that each of those metal foils and jars of gas had its own distinct personality - *Freeman Dyson, referring to the periodic table display in the Science Museum, London, which has element samples in bottles.*

In 2008, the 63rd General Assembly of the UN has ratified a resolution (A/RES/63/209) proclaiming 2011 as the *International Year of Chemistry*.[1] The International Union of Pure and Applied Chemistry (IUPAC) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) strongly believe that *it is time to celebrate the achievements of chemistry and its contributions to the well being of humankind*.[2] No need to remind us that all living processes are controlled by chemical reactions, and that our understanding of the material nature in our universe and on earth is based on our deep knowledge of chemistry and its underlying physical principles, *viz*. that is relativistic quantum theory, thermodynamics, kinetics and electrodynamics. IUPAC plans to increase public appreciation of chemistry in meeting world needs, increase interest of our young people in chemistry, generate much needed enthusiasm for the creative future of chemistry, celebrate the 100th anniversary of the Nobel Prize recipient Madame Marie Sklodowska Curie, and the 100th anniversary of the founding of the International Association of Chemical Societies.

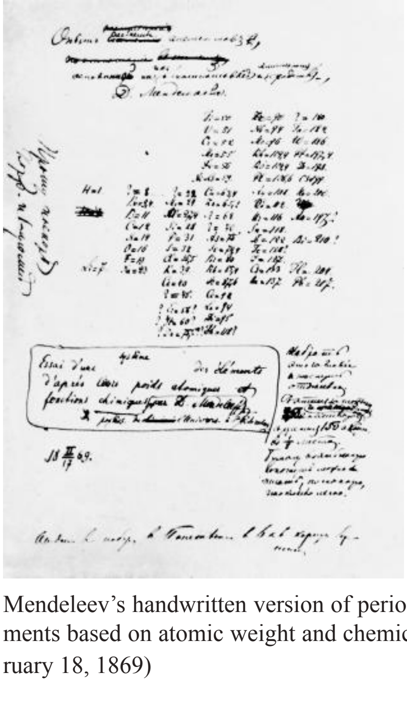
In such an eventful year we might reflect on what constitutes perhaps the most important development in the history of chemistry. This is not an easy task as many great discoveries come into our mind, all linked to outstanding chemists and brilliant minds (!), the true giants of chemistry on whose shoulders we all stand. Perhaps a look at the list of Nobel Prize winners over the last 100 years to discover some of the most influential achievements for which society would be poorer if these discoveries weren't made. Here I mention Emil Fischer's pioneering work on sugars and purines, Sir Ernest Rutherford's investigations into the atomic structure and the chemistry of radioactive substances, Marie Curie's discovery of the radioactive elements radium and polonium, Victor Grignard's discovery of the so-called Grignard reagent (which has greatly advanced the progress of organic chemistry), Alfred Werner's work on inorganic coordination chemistry, Fritz Haber's synthesis of ammonia from its elements (which is of immense value to our agricultural sector), Walther Nernst's development of thermochemistry, Irving Langmuir's discoveries and investigations in surface chemistry, Otto Hahn's discovery of the fission of heavy nuclei, Otto Diels and Kurt Alder's discovery and development of the Diels-Alder reaction, Hermann Staudinger's discoveries in the field of macromolecular chemistry, Linus Pauling's deep understanding and pioneering research into the nature of the chemical bond, Melvin Calvin's work on photosynthesis in plants, Karl Ziegler and Giulio Natta's development of high polymers (the Ziegler-Natta synthesis), Dorothy Hodgkin's structural investigations into insulin and vitamin B_{12}, Robert S. Mulliken's fundamental work concerning the chemical bond and the electronic structure of molecules by using the molecular orbital method, Gerhard Herzberg's contributions to the knowledge of electronic structure and geometry of molecules, particularly the free radicals, Ernst Otto Fischer and Geoffrey Wilkinson's pioneering work on the chemistry of the organometallic (sandwich) compounds, Vladimir Prelog's research into the stereochemistry of organic molecules and reactions, Kenichi Fukui and Roald Hoffmann's theories concerning the course of chemical reactions, Herbert Hauptman and Jerome Karle's outstanding achievements in the development of direct methods for the determination of crystal structures, Henry Taube's work on the mechanisms of electron transfer reactions, especially in metal complexes, Dudley Herschbach, Yuan Lee and John Polanyi's contributions concerning the dynamics of chemical elementary processes, Paul Crutzen, Mario Molina and F. Sherwood Rowland's pioneering work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone, Alan Heeger, Alan MacDiarmid and Hideki Shirakawa 's discovery and development of conductive polymers, Yves Chauvin, Robert Grubbs and Richard Schrock's development of the metathesis reaction in organic synthesis, and most recently Richard F. Heck, Ei-ichi Negishi and Akira Suzuki for the discovery of palladium-catalyzed cross couplings in organic synthesis.

So here we have the million-dollar question: which discovery has influenced our understanding of chemistry most? I argue that beside Dalton's early atomic theory interestingly termed *A New System of Chemical Philosophy* by him (!), and later work on atomic theory by Sir Ernest Rutherford, Erwin Schrödinger, Werner Heisenberg and Paul Adrien Maurice Dirac, it is Dmitri Ivanovich Mendeleev's discovery of the periodicity for the basic elements published in 1869 in *Zeitschrift für Chemie* (as there were no impact factors for journals at that time).[3]



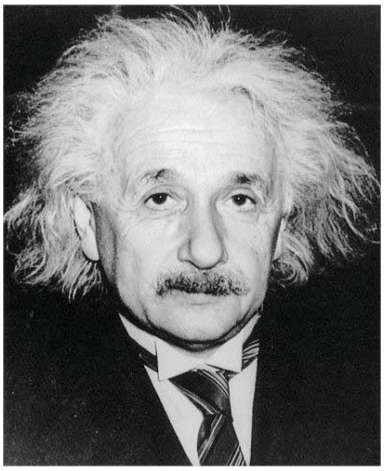
Dmitri Ivanovich Mendeleev (1834–1907)

Only one year later Julius Lothar Meyer independently announced the periodic system of elements (but Mendeleev came first and this is all that counts). Without the Periodic Table we would still be in the age of alchemy. And I guess there is not one chemist around in New Zealand who does not know the Periodic Table by heart (or at least one should hope so). For excellent historical accounts on the Periodic Table of elements see the excellent books written by Eric R. Scerri and Primo Levi.[4,5] Given this, the remainder of this article focuses on more recent developments concerning the extension of the Periodic Table into the superheavy element region.



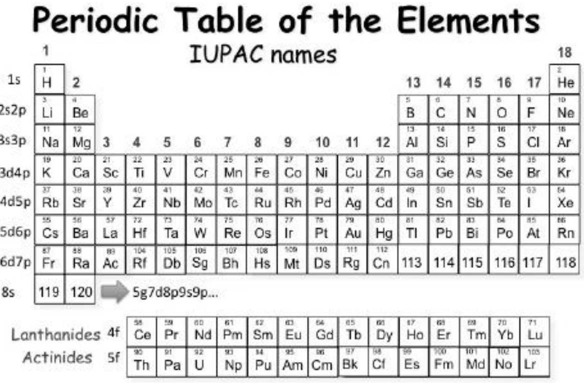
Mendeleev's handwritten version of periodic system of the elements based on atomic weight and chemical resemblance (February 18, 1869)

In the years that followed Mendeleev's discovery, the distinct gaps for the then unknown elements he left were filled successively as chemists discovered new chemical elements. This continued through the last century until the last naturally occurring element proclaimed by Mendeleev was discovered in 1939 and named francium (^{23}Fr, a daughter nucleus of ^{227}Ac, has a half-life of only 22 minutes). We all know that with the development of modern quantum theory by Erwin Schrödinger and Werner Heisenberg in the mid-1920s, and with the formulation of the exclusion principle by Wolfgang Pauli in 1925, each *row* (or *period*) in the Periodic Table corresponds to the filling of quantum shells (s, p, d, f) of electrons and to distinct electron configurations for the elements by using the so-called Aufbau (or building-up) principle as formulated first by Niels Bohr and Wolfgang Pauli. From the Janet-Madelung-Klechkowski (n+l) rule it follows that orbitals/states with lower n+l value are filled before the higher n+l ones. There are of course always exceptions to a rule as we all know, and for an excellent account on how quantum theory determines the position of an element in the Periodic Table, I recommend reading the recently published article by Shu-Guang Wang and W. H. Eugen Schwarz.[6]



Albert Einstein (1879 –1955)

Before the development of quantum theory physics went through another important revolution – Albert Einstein's theory of relativity – long thought to be rather unimportant for understanding basic chemistry. Interestingly, the birth year of Albert Einstein coincides with Mendeleev's discovery of the Periodic Table. Another major development came with Paul Dirac's formulation of relativistic quantum theory in 1929 and I quote: *The general theory of quantum mechanics is now almost complete, the imperfections that still remain being in connection with the exact fitting in of the theory with relativity ideas. These give rise to difficulties only when high-speed particles are involved, and are therefore of no importance in the consideration of atomic and molecular structure and ordinary chemical reactions, in which it is, indeed, usually sufficiently accurate if one neglects relativity variation of mass with velocity and assumes only Coulomb forces between the various electrons and atomic nuclei.*[7] And then in 1988 Sheldon Lee Glashow wrote: *Modern elementary-particle physics is founded upon the two pillars of quantum mechanics and relativity. I have made little mention of relativity so far because, while the atom is very much a quantum system, it is not very relativistic at all. Relativity becomes important only when velocities become comparable to the speed of light. Electrons in atoms move rather slowly, at a mere one percent of light speed. Thus it is that a satisfactory description of the atom can be obtained without Einstein's revolutionary theory.*[8] However, the understanding of the chemistry of the elements has changed substantially over the last three decades, as chemists slowly realized that Einstein's theory of relativity must not be neglected for the heavy elements. This is even more so the case for the newest entries in the Periodic Table, the trans-actinides, also known as the super-heavy elements that are generated synthetically and have limited lifetimes. In fact, the chemistry of the most recent extension of the Periodic Table is dominated by Einstein's theory of relativity, which Dirac could not foresee in 1929. Moreover, it is now well known and accepted that the chemistry of gold cannot be understood without the inclusion of relativistic effects. Pekka Pyykkö and Jean-Paul Desclaux pointed out in the mid-1970s that by using Dirac-Hartree-Fock calculations relativistic effects become more important in chemical bonding than originally presumed: *The orbital energies for non-relativistic AgH and AuH are quite similar while the relativistic ones are not. The non-relativistic bond lengths also agree within 3.0% while the experimental ones differ by 5.8%. This suggests that the chemical difference between silver and gold may mainly be a relativistic effect.* The unusual yellow colour of gold, the fact that mercury is the only metal that is a liquid at room temperature, the very small binding energy between thallium atoms (due to spin-orbit effects), and the unusual chain-like structures of gold halides in the solid state are prime examples for the importance of relativistic effects. The recent *gold-rush* in heterogeneous and homogeneous catalytic reactions involving gold as an efficient catalyst is also due to relativity.[9] Pekka Pyykkö wrote an excellent review article on the subject of relativistic quantum chemistry, which is also strongly recommended for reading.[10]



Periodic Table of the Elements

IUPAC names

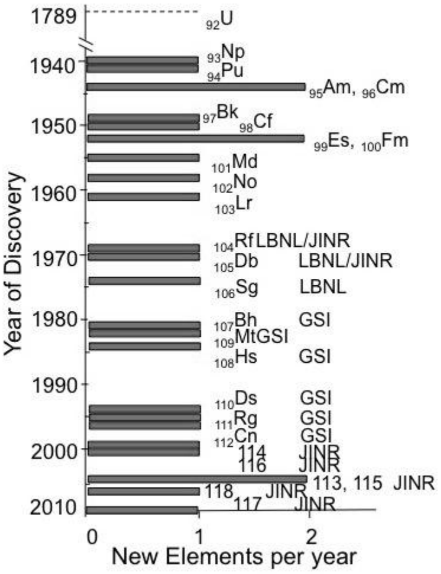
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1s	1 H																	2 He
2s2p	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3s3p	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4s3d4p	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5s4d5p	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6s5d6p	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7s6d7p	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113	114	115	116	117	118
8s	119	120	5g7d8p9s9p...															

Lanthanides 4f	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides 5f	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

The last naturally occurring element is Uranium with the atomic number of 92. The reason is that uranium has two isotopes ^{235}U and ^{238}U with rather large half-lives of 700 million years and 4.5 billion years, respectively. Heavier elements than uranium that were synthesized from neutron flux out of supernovae explosions have much smaller half-lives and were, therefore, long gone before the formation of our solar system, and so the search for trans-actinides (elements beyond nuclear charge 103, trans-fermium elements) remained fruitless. The newest additions to the Periodic Table, *i.e.* elements beyond the actinide series, are all synthesized artificially through nuclear fusion reactions that have very low production rates. It was Glenn Seaborg who pioneered the syntheses of the elements beyond uranium, and was the principal leader in the discovery of the elements from ^{94}Pu to ^{102}No, and for ^{106}Sg named in his honour while he was still alive, a unique honour to a scientist. Isolation of a sizable quantity of any of the trans-actinide elements has never been achieved. By way of example, isotope 251 of Rutherfordium (^{251}Rf) decays with a half-life of 78 seconds. For the super-heavy elements, the production rates are as low as one atom per week or month, and the synthesis of new elements requires radioactive beam facilities for neutron-rich beams and targets, to push the produced isotopes towards the predicted nuclear island of stability. The heaviest element for which atomic spectroscopy was applied to determine its atomic structure was ^{255}Fm with a half-life of 20.1 hours. This isotope was produced at Oak Ridge laboratory (USA), where a sample of 1.7 ng was chemically extracted and air-shipped to Germany for experiments, and by the time that it arrived more than 95% of the ^{255}Fm sample had decayed.[11]

Glenn T. Seaborg (1912–1999)

The newest elements that have entered the Periodic Table from 1990 onwards are Ds (Darmstadtium, 110), Rg (Roentgenium, 111) and Cn (Copernicium, 112) synthesized by the GSI Helmholtz centre in Darmstadt (Germany), and the elements with nuclear charge 113 to 118 were produced by the Joint Institute for Nuclear Research (JINR) group in Dubna (Russia) (see graph of discovery below) and are yet to be named. Chemistry on super-heavy elements can only be performed at a one-atom-at-time level, and is restricted to isotopes with half-lives of a few seconds or more. Such experiments have already been carried out for the elements up to Cn (except Mt, Ds and Rg, 109-111, respectively) in joint collaboration between the research groups at the Paul Scherrer Institute (PSI) in Villigen (Switzerland), the Society of Heavy Ion Research (GSI) in Darmstadt (Germany), the Lawrence Berkeley National Laboratory in Berkeley (USA), and the Joint Institute for Nuclear Research (JINR) in Dubna (Russia), and preparations for atom-at-a-time chemistry on element 114 are currently in progress.[12] Chemistry for such short-lived isotopes are at the most extreme limit of chemical reactions, and needs to be supported by accurate relativistic quantum chemical calculations. For the future it is highly desirable to obtain more neutron enriched superheavy elements of near spherical nuclear shape close to the predicted nuclear island of stability in order to carry out atom-at-a-time chemistry with elements of much longer lifetimes. We currently do not know how we can achieve this ambitious goal.



A history of the discovery of the heavy and super-heavy elements; GSI: Heavy Ion research centre in Darmstadt; LBNL: Lawrence Berkeley National Laboratory; JINR: Joint Institute for Nuclear Research in Dubna

Recent quantum chemical calculations suggest that Cn is an element as small as Zn because of the strong relativistic 7*s*-shell contraction, thus becoming inert to chemical reactions, and element 114 (eka-Pb) is predicted to adopt a closed shell configuration because of the large spin-orbit splitting of the 7*p*-shell. Solid Cn is predicted to be a semiconductor with a small band-gap,[13] and element 114 is a solid metal similar to Pb with a rather low cohesive energy due to relativistic effects.[14] For an excellent account on super-heavy element chemistry and the importance of considering relativistic effects, the review article by Matthias Schädel is highly recommended.[15]

The placing of the new elements in the Periodic Table up to nuclear charge 120 is firmly accepted by relativistic quantum theoretical calculations. However, the correct placing of the elements from 121 onwards is less than clear-cut. The *p*-,*d*-, *f*-, and *g*-levels are lying so close energetically that a correct prediction for the ground state configuration becomes a formidable task. According to Shu-Guang Wang and Eugen Schwarz, this causes a complete breakdown of chemical systematics.[6] However, this has not hindered Pekka Pyykkö (Helsinki) recently to propose an extension of the Periodic Table including the elements up to nuclear charge 172, thus successively filling the 8*s*, 5*g*, 8*p*, 6*f*, 9*s* and 9*p* shells.[16] This newly extended Periodic Table will certainly cause a lot of discussion within our chemistry community. To verify Pyykkö's claims, accurate quantum chemical calculations including electron correlation and perhaps even quantum electrodynamic effects are required. And whether we will see the production of more super-heavy elements and exciting atom-at-a-time chemistry in near future, we just have to wait and see.

Glenn Seaborg was a well-known advocate of science education and of federal funding for pure research. However, over the last 20 years chemistry has been through a rather bumpy and long winding road with no end in sight - and that despite the fact that so many important recent discoveries were made. Let us all hope that 2011 brings some long-deserved awareness and necessary changes to foster and support chemistry research in our country. There is no quick solution to the many difficult environmental and financial problems human kind will face in not too distant future, but I am convinced that chemistry will contribute substantially to solving these problems. We need to get on with this sooner rather than later. For this we desperately need more Mendeleev's, Rutherford's, Seaborg's, MacDiarmid's and the like, and a better understanding by our administrations of how research really works, *i.e.* in mysterious and unpredictable ways, which makes chemistry such an exciting, creative and innovative subject.

Acknowledgments

I thank Brian Halton (Victoria University of Wellington) for suggesting I write this article. The pictures shown in the article are freely downloadable from Wikipedea sites (copyright expired), and the Periodic Table created in our research centre is free for use as well.

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Chemistry in Canterbury: 1986-2010

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At the University of Canterbury

The most significant constant in the 25 years since 1985 would have to be the ongoing appointments of well qualified, ambitious, experienced academic staff in the Department of Chemistry. Financial constraints have seen the number of established positions shrink from 23 to 18 at the same time as chemistry has spilled well beyond its historical subdivisions. Teaching the current, discernable, main stream topics in the traditional areas of organic, inorganic and physical chemistry is, consequently, that much more demanding. University teachers have research interests in areas that demand proficiency in new knowledge, much of which did not exist 25 years ago.

There have been enormous improvements in analytical chemistry of all types. Modern techniques permit measurements of concentrations at the parts-per-billion level in all states of matter and some interesting applications have been developed locally. Molecular structure analysis has benefited from huge developments, particularly with increasing availability of high resolution, NMR instruments and X-ray area detectors. Applications span all research areas where new compounds are synthesized or isolated from natural sources. Both these techniques have improved in precision and speed synergistically with the increasing performance of computers and the decreasing size of microprocessors. Also, there has been professional development of sophisticated computer programs to exploit the data these instruments pour out. Computational molecular modelling has also advanced a very long way with enhanced computer power. Other applications include polymerisation kinetics and studies of complicated equilibria between the oceans and their atmospheres.

Reviewing the past 25 years of chemistry in Canterbury has required mining annual reports and soliciting personal contributions from colleagues inside and outside the Department but it is neither possible nor desirable to review all individuals' contributions. Rather, some major thrusts in chemical research are outlined and the acquisition of instrumentation and associated developments mentioned where these are essential to ongoing achievement in these areas.

Organic Chemistry

A strong interest in reaction mechanisms, founded over decades by the late Professors John Packer and Jack Vaughan, has continued to interest staff members trained in that school. Professor Michael Hartshorn pursued rearrangements of steroids, monoterpenes, cyclic sulfites and acetylenic alcohols and studied *ipso*-nitration of aromatic hydrocarbons and phenols, including reactions with fuming nitric acid and nitrogen dioxide, and the chlorination of polysubstituted phenols. Other studies involved the reactions of cation radicals generated by the photolysis of aromatic hydrocarbons.

Professor Jim Coxon has reported on the stereochemistry and facial selection in cyclo-addition reactions, developed metal mediated allylation methods and elucidated stereochemistry. He conducted photochemical studies of the use of magic acid to induce ring expansion as a means of making complex skeletons and examined fragmentation and rearrangement of these skeletons. Jim also reported on *ab initio* studies of epoxide rearrangements and intramolecular ring-forming reactions, cycloaddition reactions of alkenes and alkynes, including the effect of proximate lone pairs on facial selectivity. Modelling studies were carried out to predict conformations of macrocyclic compounds, and these were correlated with NMR studies. Software was written to correlate molecular motion with nOe build-up and to examine the secondary structure of biopolymers. Contributions have been made to the development of theozymes for intramolecular reactions and modelling has been used to study intercalation of ethidium in DNA. Most recently these methods have been used to facilitate the development of inhibitors of cysteine proteases, with particular application to slowing cataract development. Other studies have included the mechanism of ring-opening reactions of cyclopropanes, cyclobutanes and epoxides. Jim also pursued a long-term interest in diastereotopic selection in the rearrangements of epoxides.

Professor Peter Steel's research ranges over a number of areas of chemistry. The most common feature has been the presence of heterocyclic compounds; in particular, the design of new chelating and bridging heterocyclic ligands for use in coordination, organometallic and supramolecular chemistry, aspects of which have been summarised in a review (see: Steel, P.J. *Acc. Chem. Res*. **2005**, *38*, 243-250). He has been interested especially in the self-assembly of new metallosupramolecular species, such as cages, helicates (including the first ever quadruple stranded helicate), boxes, rings and coordination polymers. Other aspects include the study of new chiral ligands, the study of cyclometallated compounds and of metal-metal interactions. Peter has also been involved in the organic chemistry of heterocyclic compounds, particularly in the study of the tautomerism of heterocycles and X-ray structures of new heterocyclic compounds, in a long standing collaboration with Alan Katritzky at the University of Florida.

Biological, Medicinal and Natural Product Chemistry

For the past 25 years Professors John Blunt and Murray Munro have been managing a programme for the discovery and development of marine natural products. A large group of Postdoctoral Fellows, PhD and Honours students, and research assistants have made many fascinating discoveries resulting in numerous publications on compounds such as the mycalamides, discorhabdins, halichondrins, variolins, thyrsiferol and pateamine. All of these compounds have spawned many synthetic and biological investigations around the world.

Several of the lead compounds isolated over the years progressed in various trials for development as anticancer agents. For example, variolin B, originally isolated from a sponge collected by their group from under the Antarctic ice, is currently at a pre-clinical phase with the Spanish company PharmaMar SA. Following an innovative synthesis of variolin at Canterbury by Jonathan Morris (now at the University of New South Wales), PharmaMar prepared over 200 analogues and, based on the results, took the variolins to a pre-clinical phase.

One of the most significant results arising from the marine natural products research has been the release in November 2010 of the new anti-cancer drug Halaven, a synthetic halichondrin analogue developed by Eisai Co. (USA). The halichondrins had first been isolated from a Japanese sponge in 1985, but a 10-times richer source was found in a deep-water marine sponge collected off Kaikoura and investigated over the 1988-1995 period. The US National Cancer Institute (NCI) was very interested in obtaining a large supply of halichondrin B to extend studies they had initiated which indicated a novel mode of action for this compound in arresting the growth of tumor cells, and they organized a contract with the UC group for supply. Following an environmental impact report, one tonne of sponge was collected and extracted with the assistance of staff at NZ Pharmaceuticals in Palmerston North; it yielded 310 mg of halichondrin B. This supply enabled the NCI to carry out critical xenograft experiments in mice, the results of which encouraged Eisai Co. to continue work on halichondrin analogues that have led to the future drug Halaven. Dr David Newman, Chief of the Natural Products at the NCI, organized the New Zealand supply contract and subsequent collaborations with Eisai, and he has said: *Without the New Zealand material and the work done in NZ, none of the future development would have occurred*. The release to market of Halaven and the preclinical status of variolin B are good examples of the value of the study of natural products in the development of drugs for human and animal use.

John and Murray have recently received a number of prestigious international awards for their research contributions that include being jointly awarded the UC Research Medal and the Paul J Scheuer Award, the highest award in the area of marine natural products. The most recent was the highest award of the American Society of Pharmacognosy, the 2011 Norman Farnsworth Research Achievement Award, the first in the 35-year history to scientists from the southern hemisphere.

Professor Andrew Abell contributed to the expertise in the area of biological and medicinal chemistry. During his period at UC, his group synthesized a wide variety of biologically active molecules, mainly enzyme inhibitors. These included HIV and serine protease inhibitors and invoked novel structural motifs including photoactive molecular switches and conformationally rigid systems.

Former student and now Associate Professor, Emily Parker explores the evolution and molecular details of enzymatic catalysis. Emily has been Director of the Canterbury Biomolecular Interaction Centre and a member of the Oxygen group, a science advisory group made up of high-flying younger NZ academics who advise the government on developing trends in science to inspire their peers and younger scientists. She received a UC Teaching Award and then later in 2010 the national Tertiary Teaching Excellence Award as one of this country's top tertiary teachers.

Professor Antony Fairbanks, who visited the department in 2006 as an Oxford Exchange Fellow, was appointed to the faculty two years ago and is now Head of the Chemistry. He is a synthetic organic chemist by training, with research interests centred on the chemistry and chemical biology of carbohydrates. His group has worked extensively on the stereochemical control of glycosylation reactions, and has reported the synthesis of a variety of oligosaccharides, glycoconjugates and glycomimetics; the latter as potential therapeutic agents against a variety of disease states and infectious agents. Most recently his group has been developing biocatalytic approaches to homogenous glycopeptides and proteins.

Dr. Andy Pratt is a bio-organic chemist whose interests encompass issues associated with the chemistry of life. He has a great interest in the philosophy of science and in chemistry education, and received the UC teaching award in 2001; he is the director of Biochemistry in the Department. Professor Ian Shaw joined the university a few years ago and has ongoing interests in a plethora of epidemiological issues while Dr. Rob McKeown and Dr. Michael Lever, have continued collaborations with the pharmaceutical and medical worlds respectively.

Physical Chemistry

Professor Leon Phillips has been active in gas phase kinetics and all types of interphase equilibria for the past 25 years, and the 25 years before that! His first graduate student, Professor Murray McEwan, has developed a highly sensitive (ppb) drift tube mass spectrometer, and the company that he set up enjoys some success with forensic applications both here and abroad. Professor Peter Harland's work has been facilitated by the design and construction of specialized instruments, only some of which are described below.

In the early 1980s a drift tube mass spectrometer was designed and constructed to measure the mobilities of positive ions drifting in inert gases under the influence of electric fields. This instrument was used to demonstrate, for the first time, a significant difference in the drift properties of isomeric ions, such as $C_2H_xO^+$, and then applied to identify the isomeric form of an ion-molecule reaction product by measurement of its mobility. Mobility data were successfully inverted to calculate a large number of ion-neutral interaction potentials.

The first stage of a molecular beam machine was designed in the late 1980s as the nucleus for a crossed beam machine which was not completed until the late 1990s. Initially, the single beam machine was used to measure the physical characteristics of supersonic molecular beams and the data used to test mathematical models. This was followed by the addition of a 1.3 m hexapole inhomogeneous electric field filter as an upper Stark state selector for seeded beams of symmetric top molecules and a radio-frequency spectrometer to measure the rotational quantum state population distributions in supersonic beams of symmetric top molecules. Measurements of collisional relaxation cross-sections for upper Stark states of symmetric top molecules (ΛM_J changing collisions) gave values up to 1000 $Å^2$, which explained why ultra-high vacuums were essential to maintaining quantum state integrity during beam transmission through the machine.

This was followed by the first reported measurement of the mean lifetime for spatial de-orientation of upper Stark states after passing into field-free space. The addition of homogeneous field plates facilitated the determination of the minimum electric field strength required to retain spatial integrity for oriented beams. These measurements were needed to move on to an investigation of cross beam studies of electron-oriented molecule collisions in which fast switching electric fields were used to ensure field free conditions during electron interactions with oriented molecular beam pulses. This work showed that both the ionization cross-section and the ion products formed are orientation dependent and that as the ionizing electron beam energy is reduced the orientation effect disappears as the de Broglie wavelength of the electrons exceeds the dimensions of the target molecule. Current work is focused on the experimental and theoretical calculations of positive and negative ion collisions with spatially oriented molecules.

In addition to the molecular beam work, an instrument for the measurement of absolute total electron impact ionization cross-sections was designed and constructed in the mid-1990s that has since produced over half of all the values reported in the literature and most of those for molecules with more than 4 atoms. Measurements for several series of organic molecules (alcohols, esters, halides, cyanides and hydrocarbons) have been used to test theoretical models of electron impact ionization and have shown that the molecular polarization volume for a molecule can be reliably deduced from the maximum ionization cross-section.

Associate Professor Greg Russell works on radical polymerization kinetics. A long-standing problem in this area is that of *chain-length-dependent termination* (CLDT). One of the first chemical reactions that students learn about is that of radical-radical recombination. Because this is a near barrierless reaction, it is diffusion controlled in rate in the liquid phase. As one would intuitively expect, the diffusion of large polymer molecules is slower than that of small ones. Therefore, it is self-evident that the rate coefficient for termination in radical polymerization (RP) must vary with the size of the macro-radicals involved. Greg has been at the forefront of efforts to bring CLDT out into the open and to show that RP kinetics can only be properly understood if it is taken into account. He has developed fast computational algorithms for solving RP kinetic equations that include CLDT, and he has shown that the analytic equations from a special case of CLDT are widely applicable. The knowledge has been applied to a broad spectrum of experimental data, and has cleared up mysteries that previously were a roadblock to both accurate modeling and detailed understanding of RP systems. A particular highlight was the proposal of a new model for CLDT that, in a classic example of experiment-theory synergy, quickly found verification via a novel, EPR-based technique for measuring termination rate coefficients. A large number of monomers subsequently have been found to show this so-called composite-model behaviour. All this work was recently summarized (see: Barner-Kowollik, C.; Russell, G.T. *Prog. Polym. Sci*. **2009**, *34*, 1211-1259).

Other Specialist Spectroscopy

Dr. Rod Claridge moved EPR research from Physics to Chemistry at the university. By 1986 he was well established with his Varian E12 spectrometer and a series of successful investigations on radical ion properties and thermodynamics of ion pairing and radicals in organic single crystals were completed. Equipment was developed for one of the first EPR studies of matrix isolated radicals.

The EPR instrument was modified for single crystal studies with the intention of examining materials of technological importance. Collaboration with Dr Craig Tennant and his colleagues (from the then Physics Division of DSIR) began a study of Fe^{3+} in single crystal scheelite, calcium tungstate, which led to the development of new theory for use of Higher Spin Terms in the Spin Hamiltonian, a somewhat controversial topic. Craig retired from DSIR in 1993 and moved to Christchurch to join in studies of transient defect centres in Zircon, zirconium silicate. The next 17 years were very productive with graduate students gaining vast experience from Craig's theoretical knowledge and his practical skills in handling transient species. He also introduced Mössbauer spectroscopy for studying the site symmetries of Fe^{2+} in single crystals of ferrous ammonium sulfate hexahydrate and ferrous chloride tetrahydrate.

Professor Bryce Williamson was appointed in 1986 and has conducted research using magneto-optical spectroscopic techniques. Initially, the equipment appropriate to his research was unavailable, so he spent most of his time doing theoretical work, commuting to Paul Schatz' lab at the University of Virginia to do the necessary experiments. Most of that work involved the spectroscopy of metalloporphyrinoids doped into argon matrices at temperatures below 10 K. After a couple of years, Bryce received a UGC grant to purchase a superconducting magneto-cryostat and build a spectrophotometer. It was based on an old JASCO circular dichrograph, and could simultaneously measure magnetic circular dichroism (MCD) and absorption spectra. Subsequent work on ferricyanide represented the first measurements of MCD spectra at Canterbury.

Bryce has built a radically new type of matrix-isolation *injection* system and used it to work on metallophthalocyanines doped in argon. Students investigated spin-orbit coupling (SOC) and vibronic (Jahn-Teller; JT) effects by measuring absorption, MCD and hole-burning spectra. Other work was principally on diatomic hydrides (XH, X = C, N, O) doped in argon. In order to cope with the narrow transition line widths in his spectra, a new spectrometer was designed and constructed based on a 0.75-m Jarrell-Ash monochromator and it remains his principal research instrument.

The porphyrinoid theme was continued in the late 1990s and a new spectrometer was built to permit emission analogues of MCD to be used in a detailed study of the vibronic structure in the Q band of metallophthalocyanines in argon. An extensive generalised theory of the MCD and absorption spectra of uniaxial systems undergoing simultaneous SOC and JT effects was subsequently developed. In the early 2000s, diatomic-hydride research was developed. Measurements of the absorption and MCD of heavier species in argon and heavier noble gases required development of a dynamic theory to interpret the spectra.

This century has seen a local collaboration, with Craig Tennant and the late Cuth Wilkins, involving the spectroscopic characterisation on NZ jades. Internationally, there has been work with Spanish research groups headed by Jaume Veciana and Javier Tejada, both in Barcelona, using the temperature and magnetic field dependences of MCD to investigate hysteresis phenomena in chiral single-molecule magnets. A more applied collaboration, involving the US company Remspec Corporation, has investigated the use of fibre-optic-infrared reflection-absorption spectroscopy and chemometric methods to indentify and quantify trace amounts of pharmaceuticals on various surfaces. Recent work, with Professor Alison Downard's group, has been on the functionalization and characterization of surfaces modified with thin organic films.

Analytical Chemistry

Interest in this area waned, worldwide, prior to 1986, but it has waxed since, largely because a variety of novel and sensitive instruments have facilitated measurements with direct bearing on environmental and medical matters.

Dr. Jack Fergusson carried out environmental work on many metals and materials such as dust, aerosols, sediments, Fe-Mn nodules, tree cores, cockles, and hair and teeth. The aim was to study the environmental processing of the metals. A study of low level lead in dentine was carried out to estimate the effect of lead on children. Professor Kip Powell has been active in the Analytical Division of IUPAC for many years. He established a clean room to very high international standards and has an active interest in soil science.

Dr. Sally Gaw specialises in interdisciplinary research on the environmental fate and behaviour of contaminants, in aquatic and terrestrial environments. She is investigating the environmental fate of a wide range of contaminants including trace elements and emerging organic contaminants. This is important as it enables environmental hazards and potential remedial strategies to be identified. This knowledge underpins research in environmental toxicology and public health, as well as environmental policy.

Currently, contaminant discharges from Scott Base in Antarctica, characterization of emerging contaminants in domestic wastewater and cyanobacteria in Canterbury waterways are under investigation.

Highlights since Sally started at UC have included the purchase and installation of both a GC-MS and an ICP-MS, key to environmental chemistry research, and they have significantly enhanced her research capabilities significantly.

Inorganic Chemistry

The strength of inorganic chemistry at UC began with Dr. Cuth Wilkins in the 1950s. Dr. Jack Fergusson studied transition metal chemistry, in the preparation, structural and spectral properties (NQR, NMR, IR and UV-visible) of the halogeno complexes of metals including technetium, rhenium, ruthenium, osmium, rhodium and iridium. The late Dr. Gordon Rodley brought his original and innovative mind to bear on the convoluted structures of the DNA double helix and other origins of life biochemical topics, while Professor Don House led a long-term investigation into the synthesis and characterization of transition metals complexed with multidentate ligands.

Prof Vickie McKee was the first female permanent staff member of chemistry and is now Professor of Inorganic Chemistry at Loughborough in the UK. Her interests remain primarily focused on synthetic and structural aspects of coordination chemistry, with particular emphasis on the use of geometric factors to control metal-metal interactions and other properties in bi- or polymetallic systems. These find potential applications in fields ranging from bioinorganic chemistry to surface and solid state chemistry. Dr. Jan Wikaira's two areas of interest are investigating the magnetic properties of tetrahalocuprate complexes and transition metal macrocyclic chemistry; she also runs the X-ray crystallography facility.

Dr. Vladimir Golovko's research and teaching interests are in the area of inorganic and materials chemistry with applications in catalysis and nanotechnology. His work takes him in rather diverse directions – from carbon nanotube growth to fabrication of catalysts (from designer support materials to active ingredients - metal nanoparticles) and running catalytic testing using three different approaches. His laboratory is well connected to researchers within the university, NZ, and internationally, and is attracting a significant number of talented students. Dr. Owen Curnow works on ionic liquids while Dr. Paul Kruger is synthesizing new ligands and using them in assembling novel oligimers and other aggregates with many different metals.

Computer Impact

Like everywhere, the past 25 years has seen the exponential increase in computing power, and decrease in price with everyone now having a 1986 supercomputer on their office desk. Of course, chemical research has benefited. In addition to the advent of sophisticated professional quality software, the spectroscopic investigations alluded to above have benefited, but the two areas of research most affected have been computational chemistry and X-ray crystal structure analysis.

Dr Robert Maclagan has exploited whatever facilities he could access. These now include the university's Blue Fern supercomputer for calculations that aid experimentalists, particularly those working in the broad area of gas-phase chemical physics. Calculations have aided the identification of molecular ions by evaluating appearance potentials or proton affinities. Electro affinities, radiation energy profiles and gas phase ion motilities have been calculated; also the interaction of water with compensatory solutes and the properties of quartz when a silicon atom is replaced by aluminium and protons or Li^+ ions are present.

X-ray crystal structure analysis entered the Department through Professor Bruce Penfold. Bruce had been instrumental in acquiring the first ever computer on any NZ university campus when *Chemistry in New Zealand* was in its 50th year and he acquired the world's best software for analysing X-ray data. Combining this with microprocessor controlled diffractometers and, latterly, area detectors, Professor Ward Robinson provided a first class data service to the rest of the country and to many overseas laboratories, principally throughout Asia. Indeed, he was appointed for a term as President of the Asian Crystallographic Association from his teaching missions around countries in that area. The laboratory output has increased as a result of one structure in three days to three structures in one day. All aspects of this approach to crystal and molecular structure analysis have been replicated at former customer campuses by crystallographers trained at the Canterbury laboratory.

Chemical Education

There have been several significant contributions to education. Dr. Jack Fergusson founded the monthly magazine *CHEM NZ* (now *ChemEd NZ*), which has international circulation. School curriculum reviews have involved Departmental representatives and several teachers have spent time teaching first-year classes in the university. Extensive school visiting programs, initiated by Drs. Mckee and Steel, have extended beyond chemistry into the Science Outreach Programme largely through the initiatives of Dr. Richard Hartshorn. The initial goals were to promote the study of chemistry, and science more generally, to Year 11 pupils. Now, the programme covers all of the subjects in the College of Science and a great deal of time is spent helping teachers through workshops, *e.g.* a radioactivity workshop in collaboration with Rutherford's Den. The student presentations that were the exciting and novel backbone of the early years now seem rather mundane, but that is a measure of how technology has advanced in a decade, and of how the audience has changed. Scholarship Days and fora for Science HoDs are regular and popular activities. Dr. Robert Maclagan has been heavily involved in training the NZ Chemistry Olympiads teams with very gratifying success amongst the medalists.

Awards and Appointments

The last 25 years have seen Canterbury chemists gaining plenty of recognition for their research and teaching contributions: some in the form of DSc degrees from overseas universities (Phillips, Powell and Harland), others

Christchurch Polytechnic Institute of Technology

from UC to its own graduates – Professors Warren Roper and Robin Clark, both FRS – and to Dr. Robin Mann who completed a term as University Chancellor after a distinguished career in business. A number of the staff have been appointed Adjunct Professors in prominent overseas universities.

Many Canterbury chemists have been elected FRSNZ, some have received top national awards, and others international awards from their professional bodies. There have been several Easterfield medallists of the NZIC and four Presidents of the Institute have come from the Branch since 1986. Some of our colleagues have served on commissions of International Scientific Unions and some as leaders of international specialist interest organizations. There have been extensive contributions to important databases, particularly in marine natural products (Munro and Blunt), equilibrium constants (Powell), and thermodynamic and EPR data (Claridge).

The importance of academic visitations to the Department, both outgoing and incoming, cannot be over-emphasized. In particular, Canterbury has enormous ongoing benefits from the will of John Angus Erskine, a contemporary of Ernest Rutherford. Over the last 25 years, the Erskine Fund has allowed over 70 overseas academics to visit and share their expertise with both their academic colleagues and students in chemistry here. The Erskine Fund has also financed almost 30 trips by departmental academics to lecture and exchange research ideas overseas.

Several greatly respected people are no longer with us but deserve special mention because of their massive contributions to chemistry in the region, as well as nationally, namely: Professors Jack Vaughan, Cuth Wilkins, Stan Siemen, Drs. Jack Austin, Walter Metcalf, Gordon Rodley, and Messrs. John Pollard and Denis Hogan.

At Christchurch Polytechnic Institute of Technology (CPIT)

The 1980s saw CPIT teaching chemistry as one of the electives in the NZ Certificate of Science (NZCS). Moreover, introductory chemistry courses were also taught to students planning careers in nursing or horticulture. Since then, programmes and courses have changed to meet the demands and needs of employers, students and the government; however chemistry remains a core subject within our qualifications.

In those days, chemistry courses were taught within the Department of Science and Computing. Chemistry staff then included Dave Leuthwaite, John Cretney, Joy Causer and Dr. Selwyn Maister, who was Departmental Head for some of the time. Various part-time chemistry tutors included Mary Cretney, Jan Maister, Jan Ross, Jocelyn Douglas and Jan Wikaira.

The department moved into its current building, S Block, in 1990, which provides the chemists with better workspaces and fume hoods, and brings them into the same building as all of their scientific colleagues. Prior to this happening, science classrooms were located in different parts of the campus. The Seven Oaks horticultural site was also developed in the early 1990s and later a winery was included for students' course work on wine chemistry. A Science Advisory Committee was established so that the science courses have industry input.

The 1990s also saw greater interaction with local secondary schools, from creation of a Year 11 Chemistry Competition. Initially run in collaboration with secondary schools, CPIT staff took over this annual competition in 1996 and later expanded the scope to include competitions for Years 10–13 Science. The competitions focus on practical skills and theory with students preparing buffers, calibrating equipment, and performing qualitative functional group analyses. They continue to be extremely popular, with a capacity crowd of 25 teams always achieved, typically involving students from about 15 different schools from as far afield as Kaikoura and Timaru. Some schools always support the competitions, whereas others have come and gone a little, as pressure within the school and the priorities of individual teachers have changed.

1993 saw the creation of a Diploma in Laboratory Technology to provide science graduates with the opportunity to develop further practical skills in subjects including chemistry. This move into graduate education was also accompanied by plans to develop a research culture. In 1994, Dr Barbara Dolamore was employed full-time as a biochemistry and biology tutor, while 1995 saw Dr. David Hawke join the staff. He has made important contributions to the nascent *research culture* with his expertise in environmental chemistry, as well as his contributions to the teaching environment. A rearrangement of CPIT structure in 1966 saw the creation of the School of Science and, a year later, the NZCS was replaced with the National Diploma in Science (NDS). This change required much work for the staff in the redesign of teaching materials and assessments, and in adapting to the arguably more constrictive philosophy of Unit Standards.

In 1998, CPIT students were offered the opportunity to complete the Bachelor of Applied Science of Auckland Institute of Technology by studying additional Level 6 and 7 courses with us. These included environmental chemistry and natural products chemistry. The new degree proved to be extremely popular with students. In 1999, analytical chemist, Joe Keller, was employed to set up the Analytical and Consulting Services group to provide scientific services for industry while, in 2000, Dr. Michael Edmonds joined the staff as teacher of organic, natural products and general chemistry, and to do research in the area of synthetic organic chemistry, collaborating with Associate Professor Andrew Abell at Canterbury University.

As the research culture in the institution developed in the early 2000s, research outputs increased and external funding was sought. Success came in 2006, an impressive year in which staff were involved in three separate Marsden grants. David Hawke became an associate investigator working on DNA and stable isotopes to study moa remains with Richard Holdaway. Likewise, Michael Edmonds was an associate investigator working on novel peptide structures with Andrew Abell at CU, and Keith Baronian was a principal investigator working with Alison Downard at UC on nanobiosystems. In the same year Barbara Dolamore received a CPIT Foundation Grant to study the environmental effects of the toxic cyanobacteria in the toxic blooms on Lake Forsyth.

The end of 2008 saw the retirement of Joy Causer, a valuable member of staff, both with her teaching of chemistry and her role as Faculty Academic Co-ordinator. The science staff began work on CPIT's own Bachelor of Applied Science (laboratory technology) degree in 2009 to replace the collaborative AIT (now AUT - Auckland University Technology) degree taught for the preceding decade. The CPIT degree became available to students in 2010, the year that saw the September 4th earthquake and subsequent aftershocks. These disrupted teaching only for two weeks thanks to the diligent work of the Health and Safety staff and technicians, and to precautionary features in the laboratories; very little damage was done (five pieces of glassware broken in the chemistry laboratories).

As we begin 2011, chemistry courses still remain an important part of the now School of Applied Sciences and Allied Health. Courses provide nursing students with the knowledge to make sense of pharmacology, and science degree students with the skills to work as laboratory technicians and research assistants in a wide variety of laboratories.

Chemistry Division DSIR and ESR

Twenty five years ago ESR existed as part of the Department of Scientific and Industrial Research, or DSIR. However, in 1992 it was reconstituted as a Crown Research Institute (CRI) and rebranded as the Institute of Environmental Science and Research (ESR) Ltd., which was required be financially viable and pay its own way. Acquiring a mission statement of: *Protecting people and their environment though science*, ESR became the country's foremost provider of forensic and other scientific services.

A wide variety of analyses have been carried out at ESR over the past 25 years. The forensic group has examined clandestine methamphetamine laboratories and dealt with the fallout from the 9/11 attacks and the subsequent security paranoia centred around any and all white powders. The food laboratory has been involved in the testing of soy sauces for carcinogenic chloropropanols, measuring levels of toxic acrylamide in potato chips, checking imported spices for cancer-causing colours, and developing methods to assay foodstuffs and food packaging for the new toxin *du jour*, melamine. Each emerging analytical challenge presented its own unique analytical difficulties, highlighting one of the most profound changes at ESR over the last two and a half decades: that our analytical capability has expanded in a breath-taking manner.

Part of this rapid evolution has incorporated the mass spectrometry capability into GC and HPLC equipment, the sensitivity and specificity of which opened new vistas of possibility, leading, for example, to a GCMS project fingerprinting faecal source contamination in water by measuring faecal sterols. The recent purchase of a Liquid Chromatograph Mass Spectrometer (LC-MS/MS/MS) is being used to test foodstuffs for gluten with the aim of extending the technique to encompass a wide array of food allergens in a single analysis.

The ESR's laboratory systems employed to monitor NZ diets in the form of the *Total Diet Survey* assess exposure to chemical contaminants in food and has been exported to Fiji. The resultig Fijian Total Diet Survey was the first of its kind carried out in the South Pacific. Collaborations with the Food Safety Authority in Australia and Europe, in the form of the MoniQA (Monitoring and Quality Assurance in the Food Supply Chain) organisation continue to expand. The globalisation of ESR's food market imposes quality obligations on our exports and presents on-going health risks from abroad. Indeed, the problems of deliberate or accidental adulteration of imported products and increasingly acute consumer concerns have resulted in food forensics becoming a major growth area.

Note added by the editor: The CU and CPIT campuses were severely impacted upon by the Feb. 22 Christchurch earthquake; the university chemistry building remained unoccupied for several weeks while CPIT, itself essentially unscathed, fell within the city 'no go' zone.

Organic Microanalysis at University of Otago in its 75th Year

Arthur D. Campbell

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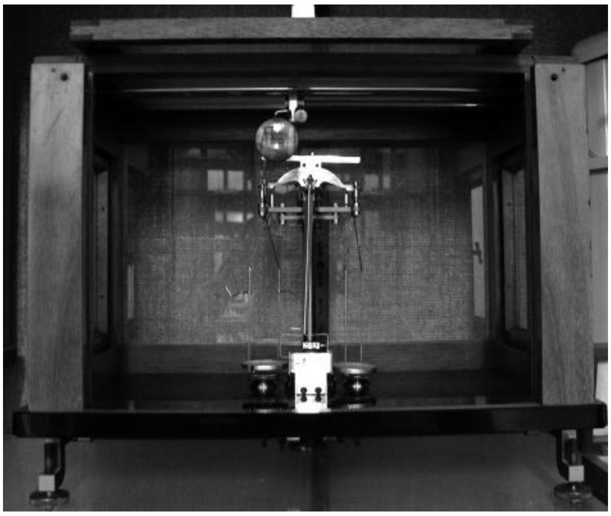
Organic Microanalysis, the analysis of organic compounds on a milligram scale had its beginnings in Austria around 1910. When Fritz Pregl, who had graduated in medicine at University of Graz in 1894, returned to Graz after further study in Europe to take up his position at the Medico-Chemical Institute he found his studies on the identification of bile acids hindered by lack of sufficient material for accurate analysis. It was while at Innsbruck University, during the 1910-13 period, that he devoted much of his time to the development of new analytical procedures and he continued this work on his recall to University of Graz in 1913 (Pregl was Vice-Chancellor of University of Graz, 1920-21 and received many awards for his work including a Nobel Prize in 1923).

Fritz Pregl asked William Kuhlmann, who worked in the balance works of Paul Bunge to refine their precious metals assay balance. By very careful design and precision grinding and alignment of the agate knife edges, he was able to produce a balance sensitive to 0.001 mg with a weighing capacity of 20 g. Pregl and his group then modified and refined the methods of organic analysis to exploit the advantage of being able to accurately weigh milligrams of sample. His very detailed procedures, which are required when working on this scale, and methods for the preparation of reagents of suitable purity were published in his 1917 monograph *Die Quantitative Microanalyse* (J. Springer, Berlin) by which time he was satisfied that the methods were suitably robust to be followed by others. This monograph was soon translated into English and later editions incorporated modifications and improvements taken from publications of other research groups. Following the award of the Nobel Prize, chemists from many countries came to the Medico-Chemical Institute at Graz to study organic microanalysis under his guidance.

When Frederick Soper arrived at Otago in 1936 to take up the position of Professor of Chemistry, he realized that the local interest in natural products chemistry at that time would be greatly facilitated if analysis on a micro scale was readily available. He obtained the necessary finance and asked Charles Carter, the Senior Lecturer in the Chemistry Department, to purchase the equipment as specified by Pregl and set up a laboratory. The Kuhlmann balance (now in a display case in the Undergraduate Building) was purchased in 1937 and the laboratory, with the appropriate equipment, was soon set up and providing a service not only for the local research group but also for some other New Zealand natural products chemists. With only the book for guidance, Charles Carter had meticulously followed the detailed procedures as set out by Pregl. Looking back, this achievement is all the more remarkable when we consider that the gas furnaces in that small basement laboratory, with its low ceiling, must have been far from ideal conditions to give reproducible moisture adsorption on glass surfaces, which was so critical in the method for carbon and hydrogen. Charlie did a lot of analyses for my MSc thesis, so many that Dr Stanley Slater (my supervisor, later Professor of Chemistry at VUC) included his name on the resulting publication.



The Kuhlmann balance purchased by the Department of Chemistry, University of Otago, in 1937 and used for organic microanalyses until 1958 - for a description of it: see text. Moving the 5 mg rider over the notched beam gives milligrams and tenths of a milligram. The next two significant figures were obtained by calculating the algebraic sum of the extreme positions of successive Left and Right oscillations of the swinging pointer over the scale. The position of the pointer had to be noted to one tenth of a division.

In 1949, the opportunity arose for the Department to develop the laboratory further when Dr. Tsu Sheng Ma was appointed to the staff. He was very well versed with the methods. After graduating from Tsinghau University in China, he studied organic microanalysis at University of Chicago where the head of the research group was one who had earlier worked with Pregl. Our laboratory was moved into larger space but still in the basement with its low ceiling. More equipment was purchased and a wider range of analyses were developed and on standby, so that the laboratory could provide a range of analytical procedures to research workers throughout New Zealand with little delay. But it was realized that Ma would return to US as soon as the opportunity arose and I was asked to understudy him whenever possible. This was to be a thorough training in the disciplined methods of a wide range of analytical procedures. T S Ma left to take up a position at Washington Square College (New York) in 1951 and I was appointed formerly to look after the laboratory in 1952.

Gradually, over the years, developments in analytical procedures and equipment have been introduced as time and funding have allowed. The University Grants Committee was very supportive of the laboratory, knowing that it was better to have one well equipped laboratory than several small units. The greatest demand is, and was for the determination of carbon, hydrogen and nitrogen, and it is not surprising that it is in this field that there has been much research and development. Initially, gas furnaces were replaced with electrical heating. Then analyzers were produced, which automated the combustion procedure, and well tested automated analyzers are available now, where the products of combustion are measured electronically rather than by weighing (carbon dioxide and water) or volume (nitrogen). However, being a service laboratory, no new procedure can be introduced until it is thoroughly tested. During my1954 study leave at Glasgow University, my interest was concerned mainly with polycyclic aromatic hydrocarbons, but I took the opportunity to visit the research groups in the microchemical laboratories at Birmingham (Ronald Belcher) and Belfast Universities (Cecil Wilson). Then, in 1957, I spent a very profitable two weeks in the CSIRO microanalytical laboratory in Melbourne, working with W. Zimmermann and his team, and this led to several modifications to our equipment. Zimmermann had worked in the laboratory at I.G. Farbenindustrie in Ludwigshafen before coming to Australia and, besides having a successful method for the direct determination of oxygen, he used air damped Bunge balances, electric furnaces and some new reagents that improved reliability.

For my study leave in 1961, I returned to the Belcher laboratories at Birmingham University, where I was assigned to work on various problems in organic analysis, particularly the analysis of perfluorinated organic compounds and submicro methods, which they were developing. Belcher was well known internationally and through his introductions I was able to visit the analytical laboratories of the pharmaceutical companies of Geigy (H. Wagner) and Sandoz Ltd. (W. Schoniger) in Basel (Switzerland), and the Royal Dutch Shell (Pete Gouverneur) in Amsterdam, as well as several in UK. Schoniger was responsible for much of the early work on the development of the oxygen-filled flask method for the analysis of halogens, *etc*. I recall Wagner saying that he did not mind spending time with me, it was not every day they had a visitor from New Zealand. The 60th anniversary of Pregl's original work was marked with a special conference in Graz, Austria, in 1970. Although few new developments in analytical procedures were disclosed in lectures, the trade display was magnificent and, besides the various analyzers and balances that were available commercially, there was also on show the beginnings of the change to today's analyzers with electronic measurement. The contact the laboratory has had with laboratories overseas has always been valuable because of the very wide range of compound types that are received and especially since many samples cannot be regarded as routine.

At Birmingham, I was present in the laboratory when about 10 cm of a quartz combustion tube disappeared in an explosion during analysis for carbon and hydrogen. Some years later, we had a similar incident in our own laboratory when analyzing organometallic perchlorates. It was not a new problem and it was soon overcome with some modifications to the procedure. At one time, we were receiving large quantities of very hygroscopic samples and the accepted Pregl method for dealing with these was tedious and not entirely satisfactory. It was while discussing this problem with a Dutch analyst at a conference in Amsterdam that I obtained sufficient information to allow us to develop a very straightforward procedure using home made aluminium foil capsules to contain the samples.

The Otago laboratory has been particularly fortunate with its staff. In the early days in particular, with gas heating and before the introduction of automated analyzers, the whole procedure for an analysis required scrupulous attention to detail and very careful observation to note anything unusual. When the number of samples for analysis was relatively small, it was usual for the staff who worked in the laboratory to have other duties in the teaching laboratories as well. Verdon Chettleburgh had a fourteen year association with the laboratory from 1951 and he maintained the service while I was on study leave in 1954 and then again in 1961. For all microanalytical work, a reference or standard substance is always analyzed with each series of samples and for the sequential determination of carbon and hydrogen and for nitrogen (the Dumas method), the first sample analyzed each day after the equipment has equilibrated is a reference sample. By operating continuously throughout the day, and eating lunch as opportunity permitted during an analytical cycle (no OSH in those days), it was possible to get through a good run of samples with just the one reference sample. It is always useful to have easy contact with those submitting samples for analysis, so that any problems can be discussed (but travel within NZ was never that easy - even attending a one day meeting in Wellington took three days!). The annual NZIC conference was particularly useful in bringing chemists together, and Verdon was able also to visit other university departments while travelling on other business. Wendy Grimmett joined the laboratory in 1957 to help with an increasing number of samples. When she left in 1963, she was replaced by Doreen Petrie and who was involved in the 1970-71 move into the new laboratory. When the new science buildings were being planned, a convenient site was found for the laboratory on the first floor of the Chemistry Undergraduate Building. The laboratory was designed not only as a service laboratory but also with space for several research students and it housed the Varian CH7 mass spectrometer as well. When apparatus (particularly balances) arrive from overseas they are in specially designed boxes to eliminate damage during transit, but shifting equipment that is already assembled and in use over a relatively long distance presents a problem. I am reminded by Doreen that the balances were partially dismantled to avoid damaging knife edges, *etc*., and then transported, one at a time, to the new laboratory. This was done by resting each balance on her lap in the front seat of my car while I drove very carefully across to the new laboratory. Later, Bob Monk joined us in the laboratory and, when he left in 1978, Bob McAllister shifted in from the undergraduate laboratories. Marianne Dick became full-time in the laboratory in1983 when Doreen left and she took over responsibility for running the laboratory when I retired in 1988. Since then the laboratory has continued to develop. In particular, it was equipped with the new Carlo Erba analyzers with electronic measurement of the combustion products for the determination of carbon, hydrogen and nitrogen which by then had been shown to be reliable. Also, with the retirement of some of the microanalysts in Australia and the cutbacks on laboratories, the local laboratory now receives samples from some Australian research groups. In 2005, the laboratory was on the move again, this time a consolidation within the Department because the large research space was no longer required. The same analytical service was provided by Marianne and Bob with occasional help from Dianne Clark during busy periods. Bob McAllister took over responsibility for running the laboratory in 2010 when Marianne retired and he has been joined by Pauline Bandeen.

There have been many incidents of note during my association with the laboratory, but one stands out. Don Hannah was involved in a project involving the fusion of samples with metallic potassium. While we were discussing this at his bench, some potassium set fire to the alcohol in the beaker he used to clean the potassium. I picked up the nearest book and put in on the beaker - (fortunately the fire went out) and carried on with the discussion. It was some time later that I was told that the book I had used to snuff out the fire contained all the results of Don's research for the year.

Some years back, when high resolution mass spectrometry became fashionable, I was told that the days of the laboratory were numbered, that mass spectrometral measurement would replace microanalysis. But the opposite has happened and sample numbers have increased. Modern instrumentation quickly provides a lot of useful information, research proceeds faster with the result that more samples are sent for analysis not fewer. And I am confident that the laboratory will continue to provide an accurate analytical service for many years to come.

Dates of Note

Apr 20 marks the 135th anniversary of the founding of the American Chemical Society in New York City. *Franz Karl* ***Achard*** died 190 years ago on 20 Apr 1821; a German chemist, he invented a process for the large-scale extraction of sucrose from beets, and opened the first sugar-beet factory, in Silesia in 1801. On Apr 23, 1951, the Associated Press started using its teletype setting service in Charlotte, NC. News article information was transmitted using a perforated paper tape. At the receiving end of the circuit, a punch produced a copy of the perforated tape that was then fed to a typesetting machine, while on Apr 28, 1926, the term *wave mechanics* was coined by nuclear physicist Erwin Schrödinger in a letter he sent to Einstein.

John William ***Draper*** was born 200 years ago on May 5, 1811. He was the English-American chemist and pioneer in photochemistry. He recognized that light initiated chemical reactions as molecules absorbed light energy. The *Draper Point* is the name given to the point at which all substances glow a dull red (*ca*. 525 °C) but he is more recognized with Theodore Grotthuss for the The *Grotthuss–Draper law* (also called Principle of Photochemical Activation) which states that only that light absorbed by a system can bring about a photochemical change. A basis for fluorescence and phosphorescence is found in this law. It was first proposed in 1817 and is considered to be one of the two basic laws of photochemistry (the second is the Stark–Einstein law). Draper's interest in spectroscopy and photography was applied to give the first astronomical photograph – the moon in 1840. He also studied photographs of the solar spectrum to show that it contained both IR and UV light. His photographs of persons include the oldest surviving photgraphic portrait (1840), and he was one of the first to produce microphotographs.

130 years ago on May 5, 1881, *Louis* ***Pasteur*** inoculated an ox, several cows and twenty five sheep against anthrax. His experiment proved successful, and was a milestone in the treatment of disease. *Victor* ***Grignard*** was born on May 6, 1871. He was the French chemist and co-recipient (with Sabatier) of the1912 Nobel Prize for his development of the Grignard reaction. *Thomas* ***Hancock***, the English inventor and manufacturer who founded the British rubber industry with his 1820 factory, was born on May 8, 1786 – 225 years ago. His chief invention, the *masticator*, worked rubber scraps into a shredded mass of rubber that could be formed into blocks or rolled into sheets. This process, perfected in 1821, led to a partnership with the Scottish chemist, Charles Macintosh, inventor and manufacturer of waterproof rubber impregnated fabric.

John Desmond ***Bernal***, the noted Irish physicist and pioneer of X-ray crystallographer, was born on May 10, 1901. *Odd* ***Hassel***, the Norwegian physical chemist and co-recipient (with Barton) of the 1969 Nobel Prize for Chemistry for his work in establishing conformational analysis, died on 11 May 1981. *Bruce* ***Merrifield***, the American biochemist who was received the 1984 Nobel Prize for Chemistry for his development of the solid phase peptide synthesis method to build up large organic molecules on a solid matrix, died 5 years ago on May 14. *Joseph* ***Loschmidt***, the Austrian chemist and physicist who was first to propose (1861) a cyclic structure for benzene and many aromatic hydrocarbons, was born on May 15, 1821. *Vincent du* ***Vigneaud*** was born on born May 18, 1901. He was an American biochemist and the winner of the Nobel Prize for Chemistry in 1955 for his work on biochemically important sulfur compounds, especially for the first synthesis of a polypeptide hormone.

Carl Wilhelm ***Scheele*** died 225 years ago on May 21, 1786. He was the Swedish chemist who discovered oxygen in 1772. He was a keen experimenter and worked in difficult and often hazardous conditions. His only book, *Chemical Observations and Experiments on Air and Fire* was published in 1777, and consequently he lost priority to Priestley's discovery of oxygen in 1774. Scheele stated that the atmosphere is composed of two gases, one supporting combustion, which he named *fire air* (oxygen), and the other, named *vitiated air* (nitrogen), prevented it.

Daniel Gabriel ***Fahrenheit*** was born 325 years ago on

May 24, 1686 and died on Sep 16, 1736, 275 years ago. He was the German physicist and maker of scientific instruments best known for inventing the alcohol thermometer (1709), mercury thermometer (1714) and for developing the Fahrenheit temperature scale. He devoted himself to the study of physics and the manufacture of precision meteorological instruments. He discovered, among other things, that water can remain liquid below its freezing point and that the boiling point of liquids varies with atmospheric pressure. On May 24, 1976, the Concorde supersonic jet began regular passenger service between Europe and Washington DC. *Carl* ***Wagner***, was the German physical chemist/metallurgist who was helped shape the field of chemical metallurgy as an exact science. In the late 1920s, with Schottky, he co-authored papers published in German journals that first organized the field of defect structures in solid-state materials; he was born on May 25, 1901. *Conrad Arnold* ***Elvehjem*** was born on May 27, 1901. He was the American biochemist who identified that nicotinic acid was a vitamin which, when absent from diet, resulted in the disease pellagra (black tongue). In 1937, working with dogs having the canine equivalent of the disease, he showed that giving a dog 30 mg of nicotinic acid resulted in substantial improvement. Continuing doses to correct the diet deficiency led to complete recovery; it worked as well in humans (niacin is one of the B vitamins). On this same day (May 27) in 1991, a patent was issued for the *production of taxol or taxol-like compounds in cell culture*. This miracle drug remains an important cancer treatment.

Alfred Otto Carl ***Nier*** was born 100 years ago on May 28, 1911. He was the American physicist who refined the mass spectrometric process to distinguish isotopes. In 1934, (with Aldrich) he applied the decay of ^{40}K to ^{40}Ar to measure the age of geological materials. He discovered (1936-38) a number of previously undetected low abundance isotopes that include ^{36}S, ^{46}Ca, ^{48}Ca, and ^{186}Os. Nier showed how the ratio of radioactive isotopes of uranium and its decay products was a second method to estimate the age of rocks. During WW II (with others) he showed that the rarer ^{235}Ur undergoes fission, and was active in the separation of these two isotopes, important in developing atomic bombs.

Henri ***Braconnot*** was born 230 years ago on May 31, 1781. He was the French chemist known for isolating glucose directly from such plant material as sawdust, linen or bark by boiling them with acid (1819). *Louis J.* ***Ignarro*** was the American pharmacologist who (with Robert Furchgott and Murad) was co-awarded the Physiology or Medicine 1998 Nobel Prize in for the discovery that nitric oxide acts as a signalling molecule in the cardiovascular system, an entirely new mechanism by which blood vessels in the body relax and widen. He was born on May 31, 1941.

Hans ***Berger***, the first to record a human electroencephalogram (EEG), died on June 1, 1941. *Charles-Bernard* ***Desormes*** was born on June 3, 1771. He was the French chemist who (with future son-in-law Nicolas Clément) determined the exact composition of carbon monoxide and carbon disulfide. *William Thomas* ***Astbury*** died 50 years ago (June 4, 1961). He was the English physical biochemist who was the first to make use of X-ray diffraction patterns to study the structure of nucleic acids in 1937. *Carl* ***Jung***, the Swiss psychologist, collaborated with Freud in Vienna in 1907-13 and then developed his own theories, which he called *analytical psychology* to distinguish them from Freud's psychoanalysis, died on June 6, 1961 (50 years ago). *Robert Sanderson* ***Mulliken*** was born on June 7, 1896 and received the 1966 Nobel Prize for Chemistry for his fundamental work concerning chemical bonds and the electronic structure of molecules.

Francis ***Crick*** was born 95 years ago on June 8 while Sir *James Young* ***Simpson***, regarded as the father of modern anaesthetics having been the first to employ chloroform for the purpose, was born 200 years ago on June 11 1811. *Julius Arthur* ***Nieuwland***, the Belgian-born American organic chemist who studied reactions of acetylene and invented neoprene, died 75 years ago on June 11 1936. *Erwin Wilhelm* ***Müller***, the German-U.S. physicist who invented the field emission microscope (FIM) that gives magnifications in excess of one million, was born 100 years ago on June 13, while *Jesse* ***Boot***, who founded the Boots Company, died 80 years ago on the same day. *Charles-Augustin de* ***Coulomb***, of Coulomb's law fame, was born on June 14, 275 years ago (1736), the same day on which 380 years ago was founded the Royal Dublin Society.

Donald J. ***Cram***, who shared the 1987 Nobel Prize (with Pedersen and Lehn) for his creation of molecules that mimic the chemical behaviour of molecules found in living systems, died on June 17, ten years ago. Sir *Frederick Gowland* ***Hopkins*** was born on June 20, 150 years ago (1861). He was the British biochemist, who received the 1929 Nobel Prize (with Eijkman) for Physiology or Medicine for discovery of essential nutrient factors, now known as vitamins, needed in animal diets to maintain health. *William H.* ***Stein***, the American biochemist who (with Moore and Anfinsen) was a co-winner of the 1972 Nobel Prize for Chemistry for their studies of the pancreatic enzyme ribonuclease, was born on June 25, 1911.

On June 25, 1921, German chemist, *Friedrich Karl* ***Bergius*** invented a way to convert coal dust and hydrogen directly into gasoline and lubricating oils without isolating intermediate products. He shared the 1931 Nobel Prize for Chemistry with German, Carl Bosch. On June 26, 1886, 125 years ago, *Henri* ***Moissan*** isolated the element fluorine for the first time. *Paul* ***Berg*** the American biochemist who made fundamental studies of the biochemistry of nucleic acids, with particular regard to recombinant-DNA, has his 85th birthday on June 30 while *Alfred G.* ***Gilman***, who shared the 1994 Nobel Prize for Physiology or Medicine (with Rodbell) for molecules called G proteins, has his 70th on July 1. Sir *Lawrence* ***Bragg*** died 40 years ago on July 1 while *Henri-Étienne Sainte-Claire* ***Deville*** (known for inventing an economic process for producing aluminium) died the same day in 1881.

The father of scientific dairying, *Stephen Moulton* ***Babcock***, died on July 2, 80 years ago. *Frederick* ***Seitz***, the American physicist who made fundamental contributions to the theory of solids, nuclear physics, fluorescence, and crystals, was born on July 4, 100 years ago, while *Marie* ***Curie*** died on the same date in 1934. The Irish physicist who introduced the term electron for the fundamental unit of electricity, *George Johnstone* ***Stoney***, died 100 years ago on July 11. *Edward Goodrich* ***Acheson***, the American inventor who discovered the abrasive carborundum, and perfected a method for making graphite, died 80 years ago on July 6. *John Styth* ***Pemberton*** was the pharmacist who invented Coca-Cola (in 1885); he was born on July 8, 1831. Sir *William* ***Grove***, the first to offer proof of the thermal dissociation of atoms within a molecule by showng that steam in contact with a strongly heated platinum wire decomposes into hydrogen and oxygen in a reversible reaction, was born on July 11, 200 years ago. *August* ***Kekulé*** died on July 13, 1896. Jun 14, 1836, saw *John* ***Ruggles*** (Maine) received US Patent No. 1, under a new system for numbering patents. Before Ruggles, there had been 9,957 non-numbered patents issued. His patent was for a traction wheel used in locomotive steam engines. As chairman of the Senate Patents Committee, he was instrumental in patent law reform – but in 1838, a Senate select committee investigated him for corruption charges relating to a patent application. Former organometallics chemist Sir *Geoffrey* ***Wilkinson*** was born on July, 14, 1921. In 1791 on July 14 chemist *Joseph* ***Priestley***'s laboratory, home and library in Birmingham were burned to destruction by a mob of people angry at his support of the French Revolution. *Bruce* ***Merrifield***, the American biochemist famed for his solid phase peptide synthesis method, was born on July 15, 1921.

Experimental use of patented inventions in research

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Research leaders worry about infringing existing patent rights while carrying out their research. Below, we look at the present legal situation in New Zealand and Australia and address the concern that by simply carrying out your research you could end up in court.

The law in New Zealand and Australia

Patents give their owner the right to stop anyone else making, using or selling their invention in a country in which the patent is granted. Carrying out any of these activities could infringe the owner's patent rights. Therefore, if a patent covers the methods, compounds or apparatus used in your lab, there is a risk that you could be infringing the patent owner's rights.

In some counties, for example the UK, there is a specific exemption from infringement if the patented invention is used for *experimental use* only. Under UK law *experimental use* encompasses research which is done privately and for purposes which are not commercial. The intention behind this exemption is to allow research be carried out with less risk that the patent owner will sue for patent infringement.

Currently, there is no such specific exemption for experimental use under New Zealand or Australian law although NZ courts have indicated that experimental use should not be considered infringement. For example, in a 1991 New Zealand court case,[1] the judge commented on an experimental use exemption and recognised the difficulty in defining a *commercial objective* saying:

> *Doubtless experimentation will usually have an ultimate commercial objective; where it ends and infringement begins must often be a matter of degree. If the person concerned keeps his activities to himself, and does no more than further his own knowledge or skill, even though commercial advantage may be his final goal, he does not infringe. But if he goes beyond that, and uses the invention or makes it available to others, in a way that serves to advance in the actual market place, then he infringes.*

Current understanding is that *experimental use* is likely to include direct investigation of the invention with a view to improving it or exploring its function and limits. However, if an invention is used as a tool for other purposes, even if carried out in a research setting, this would likely be considered to infringe the patent. For example, a patented analytical method would be infringed if it was being used in a lab to simply test samples, *i.e.* the purpose for which it was designed, but may not be infringed if experiments were being carried out to improve the analytical method.

In Australia the matter has not come up in court. It is not known if the courts would apply such an exemption, but it is likely that they would.

Changes afoot – a clearer path ahead?

A specific experimental use exemption to infringement has been included into both the new New Zealand Patents Bill[2] and the proposed amendments[3] to the Australian Patents Act. There is concern that the current uncertainty around this issue is deterring research and innovation. This uncertainty may encourage business and researchers to abandon research that could risk patent infringement or to move their research and development to countries where there is a clearer path.

The new New Zealand Patents Bill is still making its way through Parliament and may yet see changes to its content, although it seems likely that this section will remain.

In Australia, there is currently a call for submissions on the proposed amendments to the Patents Act.

The wording proposed in New Zealand and Australia is slightly different, but boh include the following activities that would be considered *experimental use* which if carried out would not infringe a patent:

- seeking an improvement of the invention (*e.g.* determining new properties, or new uses, of the invention).
- determining how an invention works,
- determining the scope of the invention, and
- determining the validity of the claims (of the patent in question).

Has this been an issue to date?

In 2003, Genetic Technologies Ltd., an Australian company with two New Zealand patents concerning non-coding DNA analysis and mapping, contacted a number of life science organisations, including Crown Research Institutes, to draw attention to their patents. They were offering licences (for a price) to allow the organisations to conduct research which they believed was covered by their patents. The matter was finally settled out of court, with agreement that the organisations would not need to pay a licence fee for use of the methods covered by the patents. The validity of the patents was also questioned. While the matter was ultimately settled, if there had been a specific exemption for experimental use, time-consuming and costly negotiations could have been avoided by at least some of the organisations.

It is unclear why this issue has not been considered in court more often. Is it that researchers are avoiding patented inventions for fear of infringement proceedings? Are patent owners turning a blind eye to research being carried out? Or is it that truly experimental use, without commercial benefit, does not come to the attention of the patent owner, and therefore no action is taken against it? Perhaps action has been taken and was settled well before the matter aired publically. In reality, it is probably a combination of all these options.

Do you infringe?

Would your research be considered *experimental use* under the above definitions? If you are *experimenting on* a patented invention and seeking to improve it or investigating its scope or function, it is likely that such actions would be acceptable in New Zealand. However, if you are *experimenting with* a patented invention and using it as a tool to further your research then you are likely to be infringing the patent and may not have a defence if the case goes to court.

If you are using a commercially produced and purchased product, then you will be licensed to use any patented inventions in the product in accordance with the Terms and Conditions of the product.

If you use inventions in your research that are not covered by a patent in your country then there should not be an issue. The only way to find this out is to search patent databases and consider what is covered by the claims of patents.

Be careful though, if you use a process that is patented in another country (but not in NZ), export of the product of that process may infringe the patent in that other country.

It should be noted, however, that patents in NZ are not published on the patent database until they are accepted, following examination by the patent office (which can take several years). Accordingly, it is possible that a pending patent application may be granted in the future that covers an invention that you are currently using. It is advisable to consult a patent attorney if these issues are of concern.

While infringement action against researchers is thankfully quite rare, it is prudent to be aware of the patent literature in your country that relates to your field. Doing this and being alert to the potential for patent infringement should minimise the risk of court action by patentees.

References

1. Smith Kline & French Laboratories Ltd v Attorney-General **1991**, *2* NZLR 560.
2. New Zealand Patents Bill **2008**, 235-242.
2. Intellectual Property Laws Amendment (Raising the Bar) Bill 2011 – Exposure Draft 17/12/2010

A reminder: if you have any queries regarding intellectual property related matters (including patents, trademarks, copyright or licensing), please contact:

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Katherine Hebditch and Tim Stirrup of Baldwins Intellectual Property in Auckland specialise in chemistry and biotechnology patents. Katherine obtained her PhD in organic chemistry from the University of Manchester in the UK in 2004. She is currently working towards registration as a patent attorney. Tim obtained his PhD in molecular biology from the University of Southampton in the UK in 2007. He is also working towards registration as a patent attorney.

Conferences

6th International Symposium on Macrocyclic and Supramolecular Chemistry (ISMSC)

3 - 7 July 2011, Brighton, United Kingdom

Poster abstract deadline: 29 April 2011

www.rsc.org/ConferencesAndEvents/RSCConferences/6-ISMSC/index.asp

Tenth International Conference on Materials Chemistry (MC10)

4 - 7 July 2011 at University of Manchester, U.K.

The flagship event of the Materials Chemistry Division, providing a showcase for materials chemistry for almost two decades. Poster abstract deadline: 6 May 2011

www.rsc.org/ConferencesAndEvents/RSCConferences/MC10/index.asp

15th International Conference on Biological Inorganic Chemistry (ICBIC 15)

7 - 12 August 2011, Vancouver, Canada

http://icbic15.ubcconferences.com/

Faraday Discussion 154: Ionic Liquids

22 – 24 August 2011, Belfast, United Kingdom.

This meeting will discuss fundamental experimental and theoretical aspects of the physical chemistry of Room-temperature Ionic liquids.

http://www.rsc.org/ConferencesAndEvents/RSCConferences/FD154/

6th International Symposium on Advancing the Chemical Sciences - Challenges in Organic Materials & Supramolecular Chemistry

2 - 5 September 2011, Beijing, China.

Part of a significant new global symposia series, supporting the launch of the new RSC flagship journal *Chemical Science*. Poster abstract deadline 8 July 2011

www.rsc.org/ConferencesAndEvents/ISACS/OrganicMaterialsAndSupramolecularChemistry/Home.asp

The 14th Asian Chemical Congress (14ACC)

The Asian Chemical Congress (ACC) is held biennially and, as a tradition, it is hosted by the member societies of the Federation of Asian Chemical Societies (FACS).

Hosted by The Chemical Society of Thailand, 5-8 September 2011, Queen Sirikit Convention Centre, Bangkok, Thailand.

There will be eight general sessions: Analytical and Environmental Chemistry, Materials and Polymer Chemistry, Physical and Theoretical Chemistry, Organic Chemistry and Green Chemistry, Chemical Education, Inorganic Chemistry, Nanochemistry and Catalysis, Natural Products, Chemical Biology and Medicinal Chemistry, and Industrial Chemistry & Innovation. Standard Registration Deadline: July 20, 2011

www.14acc.org

NZIC Conference 2011

Sunday 27 November - Thursday 1 December 2011.

The University of Waikato, Hamilton, New Zealand. Chair: Michele Prinsep - m.prinsep@waikato.ac.nz. Conference Organisers: Six Hats Conference Management,

Tel: 07 834 1398, email: amanda@sixhats.co.nz

www.nzic2011.co.nz/

2012 International Symposium on Macrocyclic and Supramolecular Chemistry (ISMSC-2012)

Sunday 29 January to Thursday 2 February 2012, University of Otago, Dunedin, New Zealand.

Please register your interest via our website *www.otago.ac.nz/ismsc2012/*

Green Chemistry 2012

20-22 March 2012, Maritim Hotel, Cologne, Germany.

International industry conference on the production of polymers and additives from sustainable sources. Deadline for paper submission: 16 September 2011

http://www2.amiplastics.com/Events/Event.aspx?code=C412&sec=1853

Grants and Awards

The Hatherton Award

Science award for best paper in physical, earth or maths and information sciences by a New Zealand University PhD, awarded annually.

The Hatherton Award is awarded for the best scientific paper by a student registered for the degree of PhD at any New Zealand University, published or accepted for publication either during their studies or within two years of the completion of the PhD in Physical Sciences, Earth Sciences and Mathematical and Information Sciences. The Hatherton Award consists of a framed certificate and $500.

http://www.royalsociety.org.nz/programmes/awards/hatherton-award/

New Zealand Post-Doctoral Fellowships

The Rutherford Foundation is offering two New Zealand postdoctoral research fellowships to outstanding PhD graduates. The fellowships include a stipend, research and conference costs for two years each.

The fellowships are two-year awards for up to two applicants per year who have recently completed their PhD. They will enable recipients to undertake full-time research programmes within New Zealand in any area of science, technology, engineering and mathematics at an eligible research institution. Deadline: end June 2011.

www.royalsociety.org.nz/programmes/funds/rutherford-foundation/nz-post-doc-fellowships/#a3

The Rutherford Foundation Distinguished Fellowship

An award of $250,000 is intended to attract an outstanding researcher of New Zealand origin, back to New Zealand. It will be offered only to an applicant of sufficiently high calibre, and will be offered in odd-years (the next closing date