NZIC Chemistry IN NEW ZEALAND

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Articles and Features

Other Columns

Comment from the President

It was with some sadness that I report Richard Rendle intends to step down from all his roles involving the NZIC from the end of 2017. Richard has been a stalwart of the NZIC Council since Grant Boston stood down in 2005. In 2006 he took up the mantle of Honorary General Secretary on the Council and later combined this with the NZIC administrator's position. Since 1997 he founded and has coordinated the writing of practice high school exams for many schools around New Zealand (currently around 250+), initially for bursary and then later for the NCEA levels. This job has netted the NZIC a significant income source over the years and has helped keep the Institute afloat during the lean times. Prior to his heavy involvement in the NZIC, Richard taught chemistry for 33 years at secondary school. He has authored or co-authored five secondary chemistry texts, written a number of articles for ChemNZ and its successor ChemEd NZ and even the odd article for Chemistry in NZ. I speak for all our members, Richard, when I say you will be missed greatly.

The torch must therefore be passed and there now exists an opportunity for someone to step into this role and help shape the future of the NZIC. The position would suit someone who has a passion for chemistry, is a good administrator with flexible time. If there is someone out there for which this position appeals then please make yourself known to myself or Richard.

It was decided at the recent Council meeting that a strategic review of the NZIC is long overdue and will be undertaken this year. It will cover all aspects of the current operations of the NZIC and consider areas that perhaps the NZIC should be more actively involved in and currently is not. As part of the remit, questions will be asked such as, do we offer value to our membership? What is the best use for the website? What areas can the NZIC be more actively involved in? I welcome comment on any aspect of the NZIC that you feel requires attention. The sub-committee working on the review consists of: Assoc. Prof. Paul Plieger (p.g.plieger@massey.ac.nz) (Chair), Prof. Penny Brothers (p.brothers@auckland.ac.nz), Assoc. Prof. Gordon Miskelly (g.miskelly@auckland.ac.nz), Assoc. Prof. James Crowley (jcrowley@chemistry.otago.ac.nz) and Dr Suzanne Boniface (suzanne.boniface@vuw.ac.nz). Please feel free to contact me or any of the sub-committee with your comments. The deadline for the end of the review will be late July with our findings and recommendations presented at the AGM at the conference in August. This is your chance to help shape the future of the NZIC.

Finally, as I finish writing this I am aware that people are putting the finishing touches on their MBIE and Marsden grant applications. I wish each and every one of you success in your endeavours!

Paul Plieger
NZIC President

Presidential handover for 2016: Ian Brown on the left, Paul Plieger on the right.

New Zealand Institute of Chemistry

supporting chemical sciences

April News

NOTICE OF AGM

The 2016 AGM of the NZ Institute of Chemistry will take place on 23 August 2016 at 5.00pm at the NZIC conference in Queenstown.

NZIC PRIZES 2016

Nominations for the Chemical Sciences, Applied and Industrial, and Chemical Education Prizes close on 30 June 2016. Details are on the web site *www.nzic.org.nz*

AUCKLAND

The University of Auckland

Research Showcase

On 8 June 2016 the School of Chemical Sciences will hold its 8th Annual Research Showcase. This event provides an excellent opportunity for PhD students to showcase their research and network with the New Zealand chemistry community. This exciting one-day event will feature postgraduate student talks, a poster session, competitions, a high-profile keynote lecture, and will be followed by a reception to bring together students, staff, industry and government researchers. More details of the Research Showcase will be published in a future issue of *Chemistry in New Zealand*.

Congratulations

Congratulations to *Christian* ***Hartinger*** on his promotion to Professor and *David* ***Barker*** and *Tilo* ***Soehnel*** on their promotions to Associate Professors! Well done all!

Congratulations to Charles Kong who became the overall winner of the Biomedical Imaging Unit (BIRU) Image Competition 2015. Charles won the prize for the Cryo-SEM image of a frozen strawberry sample showing physical damage to the ultrastructure caused by ice crystals. Charles is a PhD student from the School under the supervision of Dr *Viji* ***Sarojini***.

Left to right: Christian Hartinger, David Barker and Tilo Soehnel

Charles Kong

Successful PhD completions

Congratulations to our PhD students who successfully defended their PhD theses recently: *Peter* ***Akers***, *Nihan* ***Aydemir***, *Heru* ***De Zoysa***, *Ransi* ***Devendra***, *Nabilah* ***Ismail***, *Lisa* ***Strover*** and *Jian* ***Zhang***.

CANTERBURY

Royal Australian Chemical Institute (RACI) Physical Chemistry Division Meeting 2016

The RACI PhysChem 2016 division meeting ran from 2-5 February at the University of Canterbury. It is not too often that the RACI venture outside of Australia for their conferences so it was a real privilege to host the conference in New Zealand. The conference chair was Dr *Sarah* ***Masters*** (UC), and the committee comprised Associate Professor *Adam* ***Trevitt*** (University of Wollongong), Associate Professor *Tak* ***Kee*** (University of Adelaide), Dr *Girish* ***Lakhwani*** (University of Sydney) and Dr *Jo* ***Lane*** (University of Waikato). Leishman Associates provided invaluable conference support.

The meeting was an exciting event. There were 90 attendees, over 50 oral presentations and over 30 posters. The plenary speakers were Professor *Natalie* ***Stinglin*** (Imperial College London), Professor *Rebecca* ***Jockush*** (University of Toronto), Professor *Dwayne* ***Miller*** (Director of the Atomically Resolved Dynamics Department of the Max Planck Institute for the Structure and Dynamics of Matter (MPI-SDM) in Hamburg with a secondary appointment as Professor of Chemistry and Physics at the

Delegates at the RACI meeting in February

View from the Christchurch Gondola

University of Toronto), Professor *Peter* ***Schwerdtfeger*** (Massey University, Auckland) and Professor *Scott* ***Kable*** (UNSW). All five speakers were excellent and entertaining, with several research collaborations sparking from their lectures. Several plenary speakers also helped to judge the poster session; the prize winners were *Patrick* ***Tapping*** (University of Adelaide), *Jennifer* ***Morten*** (ANU) and *Michael* ***Scholz*** (University of Melbourne).

The conference dinner was held at the Christchurch Gondola, with delegates enjoying a spectacular sunset over the Banks Peninsula with dessert!

We were fortunate to have some generous sponsors to help make the event a success: University of Canterbury (Platinum), New Zealand Institute of Chemistry (Gold), University of Otago (Gold), Massey University (Conference Supporter), NewSpec (Conference Supporter), Lastek (Conference Supporter) and PCCP (Poster Prizes).

The conference organising committee would also like to acknowledge the many people at UC who worked tirelessly with superb grace to ensure the success of the conference – it was much appreciated.

Overall the conference was a great success, the Gondola didn't break down and there were no earthquakes... Kia Ora!

University of Canterbury

Awards

Congratulations to *Vivek* ***Poonthiyil*** who won second prize for a student poster talk competition in the MacDiarmid Student & Postdoc symposium organised by the MacDiarmid Institute, Victoria University of Wellington, 19-20 November 2015 (http://www.macdiarmid.ac.nz/event/student-postdoc-symposium-2015/). There were 15 participants in the competition from different universities all over New Zealand. Vivek's talk was on the topic *Gold nanoparticles decorated with sialic acid terminated bi-antennary N-glycans for the detection of the influenza virus at nanomolar concentrations*. The talk explained how sialylglycopeptides were successfully extracted from egg yolks and then attached to gold nanoparticles to detect the influenza virus.

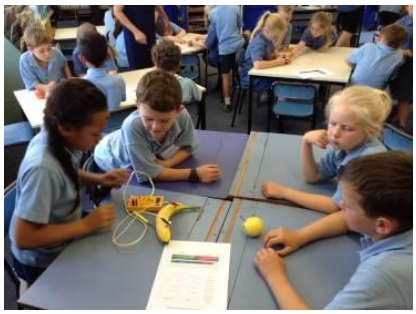
Congratulations to these PhD students who successfully defended their theses recently: *Logan* ***Heyes*** supervised by *Emily* ***Parker*** and *Nei-**Jin*** (Sabrina) supervised by *Vladimir* ***Golovko*** and co-supervised by *Alison* ***Downard***. We wish you well in your future endeavours!

Many congratulations to *Marat* ***Sibaev*** (Crittenden Group) who attended the 8th HOPE meeting in Japan last March. Applications for this were submitted to the Royal Society NZ who then nominated five candidates to the Japan Society for the Promotion of Science.

HOPE Meetings are held for excellent graduate students and early-stage researchers specially selected from countries around the Asia-Pacific region. The subject fields are physics, chemistry, physiology/medicine and related fields (including natural sciences, e.g. biology, agriculture, etc.).

The title *HOPE meeting* signifies the promise held for the future roles of young researchers and optimism for creating a bright science and technology future within the global community.

This meeting offered Marat the chance to interact with Nobel Laureates and mix with the brightest young minds in science, as well as participate in the cultural activities. Very well done Marat.


Students taking part in the 7th annual chemistry outreach

Education

Queenspark School

We recently participated in our 7th annual chemistry outreach activity with a bunch of very enthusiastic Year 3-4 students at Queenspark School. We conducted hands-on experiments with the students around the theme *From red cabbage to electrochemical fruit*. It was fantastic to be amongst such enthusiastic children and to see their faces light up as we all performed experiments using red cabbage juice as a striking acid/base indicator and testing it against various household items including vinegar, lemon juice, baking soda, detergents and dry ice (Figure, left). They then performed their own experiments in electrochemistry by deriving electricity from a range of fruit bearing appropriately inserted copper and zinc nails (Figure, centre). Indeed, they also established that a human salt bridge consisting of 53 people linked in series between Cu and Mg electrodes inserted in a potato effectively delivers the same voltage as a 1.5 volt battery (Figure, right)! At the end of the experiments we had a 15-20 minute student-driven Q&A session, which only ended when the home bell rang. These sessions continue to be a highlight in the teaching year and rank amongst our most memorable teaching experiences.

Visitors and appointments

Welcome to Bo Li, who is a visiting academic from Tangshan, Hebei, China, and who has recently joined *Paul* ***Kruger's*** group. Bo undertook his BSc and PhD degrees at Northeast Normal University (Changchun, China) under the direction of Professor Jingping Zhang, where his research was centred on the synthesis of novel magnetic materials. He was then appointed Associate Professor at North China University of Science and Technology, College of Materials and Engineering (Tangshan, China) before coming to the University of Canterbury. Bo's research interests mainly focus on molecular magnetism chemistry concerning the hybrid magnetic materials with polymer and computational chemistry involving the magneto-structural relationships. This work is underpinned by structural analysis by single-crystal X-ray diffraction complimented by a range of spectroscopic techniques with SEM and magnetic interpretation by SQUID magnetometry and computational analysis. In his leisure time Bo enjoys singing and taking photographs. He is also fond of body building to keep fit every day, and you may see him in the Ilam field running in the morning.

Bo Li

Welcome back to *Nathan* ***Alexander*** who is working as a laboratory assistant in the stage 1 prep room. Nathan is a familiar face to many as he has spent a good portion of his time in the department.

Over the years Nathan has filled numerous roles within the department including postdoc, store person, lab assistant, lab demonstrator and lab supervisor. Nathan completed his chemistry undergraduate and postgraduate degrees here at Canterbury and his Honours degree was with *Don* ***House*** and *Alison* ***Downard*** synthesising a series of dioxo rhenium complexes and measuring their redox potentials. Nathan's PhD was under *Andrew* ***Abell*** and involved preparing and assaying a series of serine protease inhibitors incorporating azobenzene functionalities that could act as molecular switches when irradiated with different wavelengths of light. Some of Nathan's interests include manga/anime, video games, computers and wood working.

Nathan Alexander

Welcome to *James* ***Shield.*** James has just started a PhD with *Alison* ***Downard*** researching aspects of surface chemistry with collaborations through the MacDiarmid Institute. James completed his Honours degree at UC after which he spent time teaching in a high school, but missed the stimulation of academia. His interests outside of chemistry are tramping, sailing and astrophotogra-

phy. He's looking forward to fitting back into the department and meeting the new faces.

James Shield

MANAWATU

Professor Shane Telfer (Massey University), in conjunction with the Institut de Recherche de Chimie, Paris, University of Leuven, Belgium and Delft University of Technology, The Netherlands, published a notable paper in Nature Chemistry in November 2015. The paper, titled *Controlled partial interpenetration in metal–organic frameworks*, reports a family of MOFs in which the occupancy level of its sub-lattices can be controlled.

Adrian ***Jull,*** Senior Tutor in Chemistry at Massey University Palmerston North retired in December 2015 after an involvement with Massey University spanning 19 years. Adrian first came to Massey as a 'born again' student completing an MSc (Hons) in 2000 before taking up a tutor position with a heavy involvement in the extramural delivery of chemistry papers. Adrian will continue his involvement in things chemical taking on the Chair of the Manawatu Branch of NZIC for 2016.

The 2016 Manawatu Branch Officers are:

Chairperson: Mr Adrian Jull (FNZIC/ Massey)

Secretary: Dr Justin Bendall (Fonterra)

Treasurer: Dr David Shillington (UCOL)

Secondary teachers professional development

In November 2015, chemistry staff at Massey University were invited by the Hawkes Bay Secondary Chemistry Teachers to provide a Professional Development Day. Four Manawatu NZIC members – *Mark* ***Waterland***, *Adrian* ***Jull,*** *Gareth* ***Rowlands*** and *Nessha* ***Wise***, ran a very successful professional development day involving demonstrations, practical activities and a keynote speaker (Gareth). The team received excellent feedback from the teachers with comments including: 'interesting', 'engaging', 'best PD all year', 'enjoyable and entertaining'. Due to the success of the Hawkes Bay trip, future events are being planned and offered to other areas in the lower North Island with the assistance of NZIC. Future events will be NZIC/ Massey events promoting NZIC and benefits to the Secondary Teachers in our region.

New students and staff

Becky Severinsen has begun her PhD at Massey University under the supervision of *Paul* ***Plieger*** and *Gareth* ***Rowlands***, with funding from a Massey University Doctoral Fellowship. Her project will involve the development of supramolecular synthons based on quinoquinoline. She completed her BSc (Hons) in 2015.

David Perl also began his PhD at Massey University this year under the supervision of *Shane* ***Telfer*** and *Geoff* ***Jameson***. His three-year PhD scholarship is funded by the MacDiarmid Institute, in which he will continue research on the partially interpenetrated metal-organic frameworks that the Telfer group recently described in Nature Chemistry. He completed a BSc (Hons) last year.

Dr Daniel Zhou has begun a three year postdoctoral fellowship under *Shane* ***Telfer*** funded by a Marsden grant exploring the synthesis and applications of multicomponent metal-organic frameworks.

A new PhD student, Ben Munro, has started working with *Catherine* ***Whitby*** and *Simon* ***Hall*** at Massey University. Ben is a Massey graduate. He completed his MSc in July 2015. For his Masters project, he worked with *Pat* ***Edwards*** and *Bill* ***Williams*** to develop new techniques for improving the quality of the structural information from NMR measurements on proteins. During his PhD, Ben will investigate the flow behaviour of emulsions using rheology techniques. His aim is to tune the interactions between emulsion drops so that he can manipulate how the emulsions yield and flow.

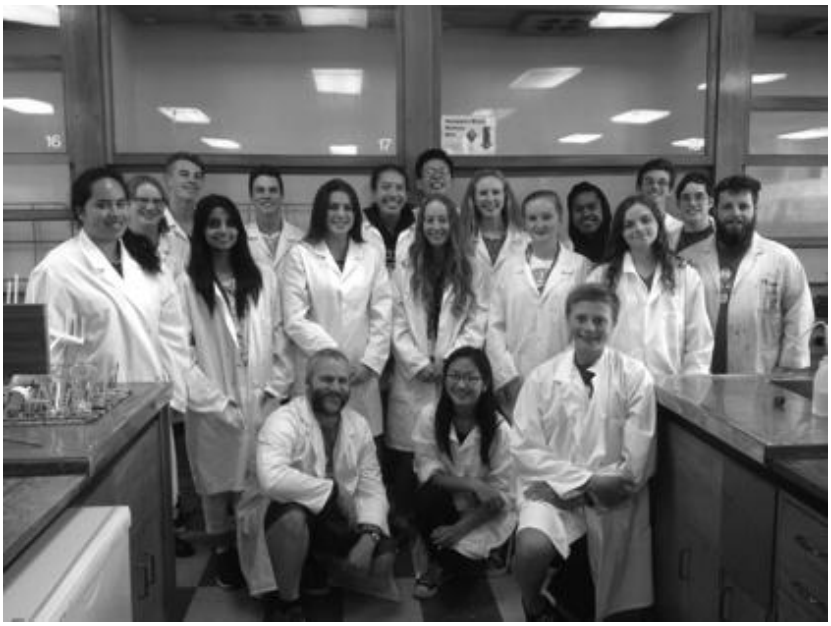
A new research technician, Dr. Rajendran Parthipan, has started working with *Catherine* ***Whitby*** at Massey University. Parthi is a graduate of the Institute of Chemistry, Ceylon in Sri Lanka. He completed his PhD in environmental chemistry in 2008 at the University of York, under the supervision of Lucy Carpenter. Parthi then accepted a position as a chemistry lecturer at the Institute of Chemistry, Ceylon. There he gained more than five years of experience in teaching analytical and physical chemistry at the tertiary level. During his one year at Massey, Parthi will investigate how emulsions containing nanoparticles spread and phase invert to form coatings.

OTAGO

University of Otago, Department of Chemistry

From 17-22 January the University hosted over 350 students from around the country for *Hands on at Otago* (formerly *Hands on science*). The Department of Chemistry hosted two project groups for the week, along with three "snack" groups in the afternoons. One of the project groups looked at natural products chemistry, using caffeine as a case study. They isolated it from semi-natural sources, synthesised it and then characterised their products spectroscopically. The second group made silver and gold nanoparticles, looking at the redox chemistry involved and how the gold particles could be used as a biosensor.

The following week we also hosted the Otago University Advanced Schools Science Academy (OUASSA), set up to provide support for students from low decile and rural schools. This year the program host-



Hands on at Otago chemistry project team, led by *Dave* ***McMorran*** (front, left), *Marina* ***Roxburgh*** (second from left) and *Aidan* ***Mackay*** (far right).

OUASSA students measuring the stress of their tough gel

ed 58 students and around 20 teachers. The main focus of the two days was the preparation of a nanoclay/*N*-isopropylacrylamide (NIPAM) based tough gel and testing its properties. The experiment is based on research being carried out in the department and was designed by a student, *Sam* ***Sutherland***.

The Department featured proudly at the 2016 University of Otago Summer School Teaching awards; *Casey* ***Davies*** (PhD student, Jameson group) was shortlisted for the top tutor and *Dave* ***Warren*** shortlisted for top lecturer.

Congratulations to *Chris* ***Larsen*** who has successfully defended his PhD and is set to graduate in August. Chris has published four papers from this thesis work including research on large dipole metal complexes. Chris will continue work as a short term research assistant for *Keith* ***Gordon*** and *Nigel* ***Lucas***. *Geoffrey* ***Smith*** submitted his PhD in conjunction with his collaboration with Fonterra. *Geoffrey* ***Smith***, *Greg* ***Huff*** and *Jonathan* ***Barnsley*** (PhD students in the group of Keith Gordon) were selected to present talks at the 11th Australasian Conference on Vibrational Spectroscopy (ACOVS11/ ACS6) in Sydney. Geoffrey presented *Imaging processed cheese components using Raman microscopy*, Greg presented *Coupling between excited states in TPA-substituted pyridyltriazole complexes* and Jonathan presented *Donor-acceptor interactions of 2,1,3-benzothiadiazole push-pull dyes; an experimental and computational study*. *Jeremey* ***Rooney*** was also selected to present the poster *Evaluation of vibrational spectroscopic methods to identify and quantify adulterants in herbal medicines* and all four students were recipients of Dodd-Walls travel scholarships.

Whilst on a short OE, *Hannah* ***Davidson***, a PhD student in Brooker's Bunch, spent an invaluable week working in the labs of our collaborator Professor Charlotte Williams (Imperial College London). Reece Miller graduated with a PhD in December and departed Brooker's Bunch after Christmas to start a postdoc with Professor Nils Metzle-Nolte in medicinal inorganic chemistry at Bochum University, Germany. We have since welcomed *Fabrice* ***Karabulut***, fresh from his MSc in Strasbourg, as he has taken up a MacDiarmid-funded principal investigator PhD scholarship. Professor Roberta Sessoli (Florence) visited us for a week during which time she gave some tutorials and a department seminar, as well as working with us on progressing a collaborative paper. *Sally* ***Brooker*** is currently busy starting to organise the second, student-focussed, SANZMAG magnetism workshop, SANZ-O-MAG2, which will be held at the University of Otago, most likely 8-10 February 2017 (to fit round AMN8, Queenstown, 12-16 Feb 2017). Once dates and venue are confirmed, there will be links from Sally's, and the MacDiarmid, websites, to a website for this workshop.

Kimberly ***Hageman*** has been appointed Associate Editor of the Elsevier journal, Environmental Pollution.

Rob ***Middag*** attended the 2016 Ocean Sciences Meeting in New Orleans in late February. Mario Hoppema from the Alfred Wegner Institute for Polar and Marine Research, Germany, is visiting the

Middag group for five months.

Masters student with *Guy* ***Jameson***, *Sekotilani* ***Aloi*** was awarded a poster prize at the 7th Joint Meeting of the Society for Free Radical Research Australasia and Japan in Christchurch, December 2015.

The inaugural *Inside the Nobel* lecture was held at the Otago Museum in December 2015. *Nigel* ***Perry***, along with speakers from the Departments of Physics and Biochemistry, delivered a public lecture explaining the science behind the 2015 Nobel Prizes in Physics, Chemistry and Medicine.

There were a large number of attendees from the Department of Chemistry at the Pacifichem conference in Honolulu, Hawaii, December 2015. Invited lectures were presented by *Sally* ***Brooker*** (*Frontiers of molecular magnetism* and *Functional molecular materials and devices* symposia), Keith Gordon (*Latest development of advanced vibrational spectroscopy* symposium) and *Guy* ***Jameson*** (*Dioxygen activation chemistry of metalloenzyme and models* symposium). Contributed lectures were presented by *James* ***Crowley*** (*Innovative approaches in bond-cleavage and bond-forming reactions at late transition-metal centres* and *Functional nanomaterials based on coordination chemistry* symposia), *Carla* ***Meledandri*** (*Organic, inorganic and hybrid nanoparticles: synthesis, characterisation and applications* symposium), *Dagmara* ***Jaskólska*** (*Nanocrystal synthesis, characterisation, assembly and applications* symposium), *Anna* ***Garden*** (*Interplay between theory and experiment in catalytic research* and *Frontiers of metal clusters and nanostructures: from fundamental properties to functionalities* symposia) and *Jaydee* ***Cabral*** (*Advances in polymers for medicine* symposium). *Shailesh* ***Goswami*** presented a poster.

Attending the 9th Australasian Organometallic Chemistry Meeting (OZOM9) at the University of Sydney in December 2015 were *Nigel* ***Lucas***, along with *Synøve* ***Scottwell*** and *Roan* ***Vasdev*** (Crowley group). At the closing it was announced that the next meeting (OZOM10) will be held at the University of Otago, 10-13 January 2017, with the student focus of the conference series to continue.

University of Otago, Department of Pharmacy

Allan ***Gamble***, *Joel* ***Tyndall*** and *Siddharth Sai* ***Matikonda*** attended the Pacifichem conference in Honolulu, Hawaii in December 2015.

WAIKATO

The Waikato Branch Committee for 2016 is as follows:

Chairperson: Michael Mucalo

Treasurer: Michael Mucalo

Secretary: Raymond Onyekachi

Council Delegate: Michèle Prinsep

Chemistry Education Group Representative: Jo Lane

Student Representative: Raymond Onyekachi

Student Liaison Representative: Bill Henderson

Branch Editor: Michèle Prinsep

Committee Members: Jo Lane, John McDonald-Wharry, Brian Nicholson, Michèle Prinsep

Note that this is subject to ratification at the AGM.

University of Waikato

Michèle ***Prinsep*** and *Jo* ***Lane*** both attended Pacifichem 2015 which was held in Honolulu, Hawaii from 15-20 December 2015. Michèle was Acting President for the conference and also gave a talk on one of her projects on Malaysian fungal metabolites whilst Jo was one of the organisers of the symposium *Reactive ntermediates in combustion and atmospheric chemistry* and gave a talk on spectroelectrochemistry of ferrocene derivatives.

WELLINGTON

The Wellington Branch kicked off the year at its 10 February meeting which featured Professor *Simon* ***Pyke*** from the University of Adelaide. An organic chemistry teacher and researcher, Simon is also heavily involved in improving the engagement and retention of students in STEM (Science, Technology, Engineering and Mathematics) subjects. In *The future: whither (wither?) STEM?*, he presented some sobering statistics from Australia about the state of STEM teaching at school and university levels, despite the eminent importance of science to the country's wealth. He spoke about the political and social reasons for non-continuation into STEM subjects at university, as well as teaching practices.

The following day, Wellington hosted the NZIC Tertiary Chemistry Teaching Symposium, organised by *Suzanne* ***Boniface*** and with about 20 participants from across all our major universities. Simon Pyke (Adelaide) presented on *Student attitudes and approaches to learning chemistry* and *Regulation, standards, outcomes and professional accreditation: meeting in the middle*. The latter described the central role of the Royal Australian Chemical Institute (RACI) in framing the higher education model now being implemented in Australia, by providing the bridge between government policy makers and academia, with exhortations for the NZIC to become more involved in educational policy development in New Zealand! The presentation about student attitudes and approaches showed the strong linkages between the mathematical preparation of the student (from school) and success in chemistry courses at university. Furthermore, the emotional engagement of the student with course material has more effect on the grade than intellectual accessibility. *Mark* ***Waterland*** took the audience through a guided inquiry exercise on energy, showing the connections between topics taught; *Marie-Anne* ***Thelen*** described development of guided enquiry lab projects; *Sheila* ***Woodgate*** demonstrated some recent innovations in BestChoice, particularly in the drawing of organic chemistry structures; *Sarah* ***Masters*** talked about new initiatives in outreach to secondary school students in order to attract them to university chemistry and *Suzanne* ***Boniface*** described the challenges facing first-year university students due to the change in style of teaching from school to university.

The Wellington Branch congratulates and thanks *Bradley* ***Williams*** for his contributions as a member of the Branch Committee and to the Branch. Bradley has recently moved to a professorial position at the University of Technology in Sydney.

Wellington has recently seen something of a surge of new arrivals in the form of babies to NZIC members. Congratulations to *Justin* ***Hodgkiss***, *Wendy* ***Popplewell***, *Shivali* ***Gulab***, *Bridget* ***Stocker*** and *Mattie* ***Timmer*** (apologies to any missed off this list).

Wellington Branch thanks *Brian* ***Halton*** for his long-standing and immense contribution as Branch Editor. His replacement is *Joanne* ***Harvey***. News items for the Branch News should be sent to *joanne.harvey@vuw.ac.nz*

Victoria University (VUW)

Kimberley Savill, a Victoria University graduate who completed her chemistry Honours degree last year (research project with *Matthias* ***Lein***) has been awarded a Rhodes Scholarship to study for a DPhil at the University of Oxford. Kimberley was a recipient of the NZIC VUW chemistry prizes at each level of her study.

Ryan ***Schwamm***, a PhD student in the group of *Martyn* ***Coles***, was awarded a VUW Research Excellence Award from the Post-Graduate Students Association late last year. Ryan has already published five research papers, including one in the prestigious *Angewandte Chemie* journal and has recently joined the NZIC. Welcome Ryan!

Russell Hewitt, previously an NZIC member and a Victoria University graduate, was in Wellington recently and gave a seminar entitled *Synthesis and fragmentation of 1,4,2-oxathiazoles* in which he described some of the work being conducted in the Institute of Chemical and Engineering Sciences at the A*STAR in Singapore. He also met with members of staff and students from *Joanne* ***Harvey***'s research group, of which he is a past member (2005–2010).

As well as *Bradley* ***Williams***' departure from the Ferrier Research Institute in mid-March, *Nicola* ***Gaston*** from the School of Chemical and Physical Sciences has also left Wellington. Nicola took up a position at the University of Auckland, in the Department of Physics, at the beginning of March.

John ***Spencer*** has taken up the role of Associate Dean (Research and Innovation) at the Faculty of Science of VUW.

A book by *Brian* ***Halton***, entitled *A cat of nine lives – and the beat goes on*, is now available online for free download (Google search using the title), documents his experiences of living with heart disease and was published late last year. It provides fascinating information about the medical processes and hope for those with similar conditions in the full and successful life that is still possible. Brian and his book recently featured on the front page of a Wellington newspaper!

Research on trapping pests using pheromone-based lures by *Rob* ***Keyzers*** and ecologist Wayne Linklater has featured in a Listener article by Rebecca Priestley on 13 February, entitled *Trappings of success*.

BRANZ

Catherine ***Nicholson*** *and Katy* ***Stokes*** joined BRANZ at the start of the year working with *Trish* ***Shaw*** in the Better Buildings research team. Trish attended the Australasian Corrosion Association (ACA) annual conference in Adelaide in November 2015 where she presented a paper co-authored by *Nick* ***Marston*** entitled *Reliable durability prediction of polymeric materials.* Trish has been selected to give the PF Thompson Memorial Lecture at the 2016 ACA conference being held in Auckland later this year. The Wellington Division of the NZ Branch of the ACA held a meeting on 8 March at which Zhengwei Li gave a talk on *Corrosion research at BRANZ* which was followed by the AGM.

NZIC Conference 2016 (NZIC-16)

21-24 August 2016, Millennium Hotel, Queenstown

Abstract submissions close 30 April 2016

NZIC-16 will host the 4th Supramolecular Chemistry in New Zealand and Australia meeting (**SCiNZA-4**). We therefore extend a special invitation to Australasian researchers in the field of supramolecular chemistry. Professor Peter Stang will present the supramolecular chemistry plenary talk, and one of the parallel sessions of the conference will be set aside for SCiNZA-4 talks. SCiNZA-4 delegates should register and submit abstracts via the main conference portal.

The conference will be held in the Queenstown, New Zealand at the Millennium Hotel from 21-24 August 2016. It is the latest in a series of biennial conferences celebrating chemistry in New Zealand and showcasing research from around the globe. The program includes plenary lectures from Donna Blackmond, Sam Kean, Peter Schwerdtfeger and Peter Stang and will include keynote lectures, invited presentations and poster sessions. The broad range of chemistry covered in the conference will be attractive to all chemists from academia, industry and will be particularly informative for student delegates.

www.nzic16.org

Article

The International Year of Light chemistry spectacular

Suzanne Boniface

School of Chemical and Physical Sciences, Victoria University of Wellington, PO Box 600, Wellington 6140 (email*: Suzanne.Boniface@vuw.ac.nz)*

Keywords: *light*, *periodic table*, *demonstration*, *outreach*

In today's world we expect to be able to light our way by the flick of a switch to turn on an electric light. In days gone by, however, the only way of making light was by using chemistry. To celebrate *International Year of Light, 2015*, Dr Peter Wothers was invited to come to NZ to present his action-packed demonstration lecture which chronicles the history of light and some of the elements involved in mankind's quest to find convenient ways of lighting their world. The following summarises the elements covered by description and demonstration in the light show.

Peter began with ***carbon***-based materials, with probably the earliest domestic lights, oil lamps and candles, being powered by fats and oils burned in oxygen to produce a flickering yellow light**.** In more recent years other carbon based fuels, particularly the hydrocarbons, have become more available and we were entertained by a comparison of brightness and soot content of the light produced by the spectacular combustion reactions of alkanes, alkenes and alkynes. In particular, ethyne gas mixed with pure oxygen was ignited to great effect in a plastic rubbish bin, producing a loud explosion and destroying the bin.

Phosphorus was the second light-producing element to be considered. Its name means 'light bringer' and we were treated first to entertaining stories of how the element was discovered and then to an alchemists' display of burning phosphorus (yes, we did manage to find some in NZ to use for this event!).

Calcium was the next element to be considered. It had a role in early theatre where chalk, calcium carbonate, was heated in an oxy-hydrogen flame to produce quicklime (calcium oxide) which glows with a brilliant light: the origin of the term 'limelight'. The flammable nature of hydrogen gas used to produce limelight for theatrical productions was illustrated by exploding a hydrogen balloon. Such an explosion was responsible for burning down a theatre in Drury Lane in London and lead to the demise of limelight as a light source.

Light from gas mantles such as those used in camping lanterns was next to be considered. This light source was discovered in the 1870s by accident when the solutions being used by a chemist boiled over onto his gauze mat, which gave out a bright white light. The gas mantles are usually made of fabric impregnated with oxides of ***magnesium, lanthanum, yttrium*** and ***zirconium*** and they give out a bright light when heated in a flame. The radioactive nature of a ***thorium*** dioxide mantle was demonstrated – a good reason for the use of such mantles to be discontinued.

The need for a strong light source came with the advent of photography. Initially ***magnesium*****,** which produces a bright light when burned in oxygen was used for a flash light. However, we saw that mixing magnesium powder with aluminium powder and sodium perchlorate produced a much brighter, more spectacular light.

We saw how other metals light up when heated, for example ***iron*** wool burned in a flame produces a sparkling effect put to good use in fireworks. More useful was the element ***tungsten*** which has the highest melting point of all the metals. However, even tungsten heated in the presence of oxygen produces an oxide whereas a sustainable light is achieved in an ***argon*** environment such as that used in filament light bulbs. Halogen lamps which also have a tungsten filament in ***iodine*** or ***bromine*** vapour were shown to provide a brighter, longer-lasting light.

Brightly glowing lights in a glass tube, often used for advertising illustrated how light can be generated when a voltage is applied to colourless gases such as ***mercury, neon, helium*** and ***argon*** each of which produces its own characteristic colour. Such light was first discovered in 1675 by a French astronomer who had a barometer with mercury at very low pressure. The barometer came into contact with static electricity and lit up. A yellow ***sodium*** street lamp which works on the same principle was also displayed. Such a lamp contains small lumps of sodium metal and comes with packaging containing a caution against allowing the sodium to come into contact with water. The reaction of sodium with water was demonstrated using a good sized chunk of sodium added to water in a specially constructed tank and a spectacular display of heat, light and sound was observed.

Another way of generating coloured light was seen when salts of the elements ***copper, strontium, sodium, potassium*** and ***lithium*** were burned. The uses of such salts were also seen in the different colours displayed when a couple of fireworks were ignited.

Light was observed from a number of different chemical reactions which do not involve combustion or burning. For a special effect we were treated to the 'barking dog' reaction – a mixture of ***nitrogen monoxide*** and ***carbon disulfide***, ignited in a long narrow tube producing a spectacular wave of light and a sound like a barking dog. Another light-producing reaction we saw was the oxidation of luminol with bleach. The resulting 'glow in the dark' effect, known as chemiluminescence, can also activated by the ***iron*** in haemoglobin. This was shown to good effect by mixing a few drops of Peter's own blood with luminol in a darkened room and we were reminded of the way this reaction is used to detect blood in crime scenes.

Having made light through a number of different sorts of chemical reactions, Peter then moved on to illustrate some historical and recent applications of light. He began by using light to generate electricity from solar panels made out of ***silicon, gallium*** and ***arsenic*****.**

Then he showed how light energy can be used to bring

about chemical reactions such as in photography where white ***silver*** chloride is converted by light energy to silver particles, thus producing a different colour on the photographic plate. Phosphorescent materials that absorb energy when exposed to light of a particular energy were next on display. A phosphorescent sheet was exposed to light of different wavelengths with yellow, green and red having no effect, and blue and ultraviolet having the best effect. A similar range of different coloured light was also used in an attempt to start a reaction between hydrogen and ***chlorine*** gases with success only coming with the blue light. The resulting reaction, carried out in a glass tube, forcefully exploded a cork from the end of the tube.

Fluorescent materials which absorb the ultraviolet light which we cannot see and convert it into useful coloured light were demonstrated including their use in fluorescent tubes for domestic lighting. Such materials contain the elements ***cerium, europium, gadolinium*** and ***terbium.***

Close to half of the elements in the periodic table were demonstrated to be involved in producing light in various forms down through the ages. During the presentation, these elements were identified by members of the audience who had been supplied with laser pointers and competed to be the first to find the elements, as they were mentioned, in a displayed periodic table.

In the grand finale, light energy was used to power a solar car carrying a lighted sparkler towards a metal '*bird*' covered in gun cotton. The gun cotton exploded and ignited a hydrogen balloon finishing the show with a loud bang.

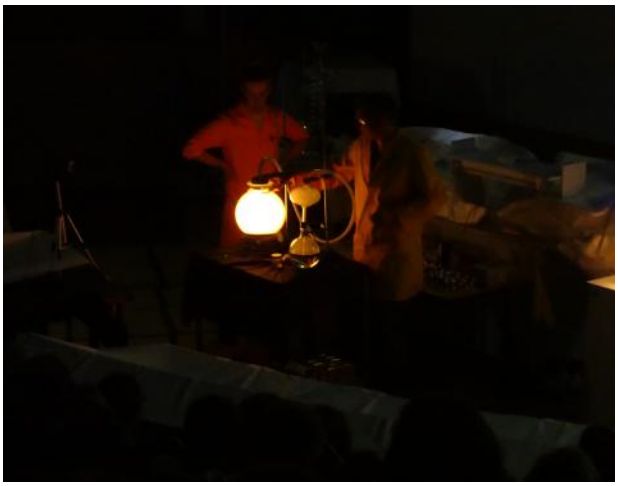
This was a most entertaining, exciting and educational performance. For the young children there was the excitement of the flashes, bangs and colours to keep them on the edge of their seats. Throughout the whole performance the chemistry and the stories were interwoven in such a way as to be easily accessible for both chemists and non-chemists.

About Peter Wothers

Dr Peter Wothers is a Teaching Fellow in the Department of Chemistry, University of Cambridge and a Fellow and Director of Studies in Chemistry at St Catharine's College. In 2014 he was awarded an MBE for services to chemistry. He actively promotes chemistry in high schools and to the wider public, including a number of online demonstration lectures that can be accessed at http://wothers.com.

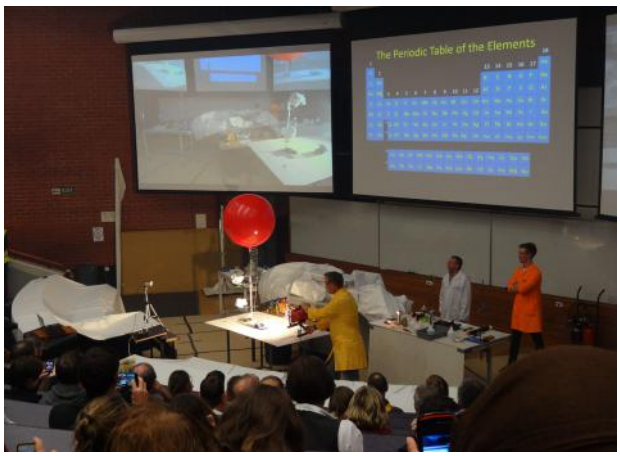
Peter performed his light show multiple times in Wellington and Palmerston North, including at the opening of the Chemistry and Biology Teachers' conference Bio-LiveChemEd2015. His visit was sponsored by the NZ Institute of Chemistry and the Wellington and Manawatu Branches, Victoria University of Wellington, Massey University, The Royal Society of NZ, the MacDiarmid Institute and the Royal Society of Chemistry.

Peter Wothers demonstrates some explosive chemistry. Photo credit: John Holman, Department of Chemistry, University of Cambridge



The glow of phosphorus – the "light bringer" glows on exposure to oxygen. Photo credit: Joanne Harvey

Peter in action relating the colours of fireworks to the elements in the periodic table. Photo credit: Joanne Harvey



The grand finale – light energy powers a solar car bearing a lit sparkler towards gun cotton-covered structures which will ignite the red hydrogen balloon. Photo credit: Joanne Harvey

Article

Chemical tools for the reduction of nitrates

J. Robin Fulton,* H. Putri Fraser, Loc Tran

School of Chemical and Physical Sciences, Victoria University of Wellington, Wellington
(email: *j.robin.fulton@vuw.ac.nz*)

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Overview

This review summarises recent work in the area of the chemical reduction of nitrate using zero-valent metal (ZVM). ZVMs have been used for the *in situ* remediation of contaminated groundwater, usually in the form of a permeable reactive barrier (PRB) that traverses the flow of groundwater.[1] These PRBs are an alternative to the costly pump-and-treat methods of highly contaminated sites. ZVM-based PRBs help to remove a variety of different contaminants including, but not limited to, heavy metals, nitrobenzene, halogenated hydrocarbons, DDT and nitrate. In the last decade, research has focused on nano-sized zero valent iron (nZVI), which has an enhanced reactivity due to its high surface area. Several sites in the USA have used nZVI to clean up highly contaminated sites, particularly those with significant levels of chlorinated hydrocarbons, such as trichloroethylene (TCE), or other pollutants such as chromium(VI).[2] Although ZVM-based PRBs and nZVI can be used to remove nitrates from groundwater, they have not been utilised in New Zealand. However, the recent Environment Aotearoa 2015 report highlighted the role elevated nitrogen is having on the quality of our fresh water[3] and it is useful to look at the reductive chemistry of nitrate by ZVM and nZVI to determine whether this technology will be useful for New Zealand. As the field of nitrate removal is bountiful, the reader will be directed to other reviews on subject matters related to the chemical methods discussed within.

Background

The state of New Zealand waterways

The state of the waterways in New Zealand is important from both health and economic perspectives.[4] Agriculture, tourism and hydroelectricity all rely on a plentiful and clean water supply. As such, the Ministry for the Environment routinely reports on the quality of fresh water across New Zealand. In these reports, total nitrogen in waterways is considered one of the national indicators of water quality. Although generally not toxic to humans at levels found in most waterways, concentrations above 0.5 ppm N as nitrate are considered high enough to trigger the growth of nuisance slime and algae. This growth affects the amount of oxygen available, coats the riverbed, and removes valuable food sources for fish and other aquatic organisms. Some species of cyanobacteria, or fresh water toxic algae, can be particularly problematic in making the water unsafe for drinking, swimming or fishing. The Environment Aotearoa 2015 report estimated that 49% of sites monitored by NIWA have levels of nitrogen greater than the trigger value.[3] Fortunately, only 1% of these sites have enough nitrogen to be directly harmful to fish.

The amount of nitrogen that has leached into New Zealand soils has increased by 29% since 1990, with that in rivers increasing by 12% during the same time period. Much of this increase is attributed to a doubling of the number of dairy cows and the increasing use of fertilisers to support this livestock.[5] In 1990, sheep accounted for greater than 53% of the nitrogen leaching to soils, with dairy cows and fertilisers contributing 23% and 4%, respectively (Fig. 1).[6] By 2008, dairy cows overtook sheep as the main contributor to nitrogen leaching, and by 2012, dairy cows contributed 36% of the nitrogen, with sheep accounting for 27% and fertiliser contributing 19%. Although the total number of sheep in New Zealand is almost an order of magnitude greater than dairy cows (31.3 vs 4.6 million, respectively), cows produce approximately ten times the amount of nitrogen than sheep per head.

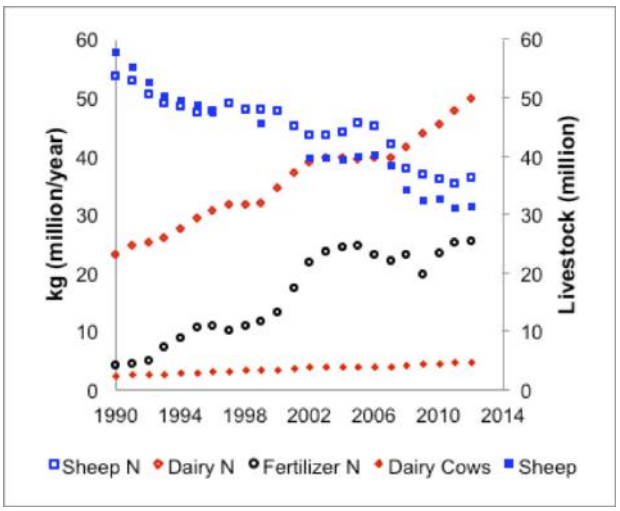


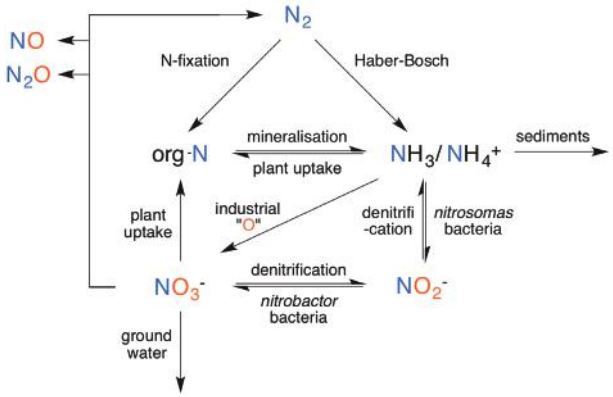
Fig. 1. The amount of nitrogen (N) leaching into soil from sheep, dairy cows and fertilisers (open markers, see key) between 1990 and 2012. The corresponding number of dairy cows and sheep are shown as closed markers.[5,6]

Fortunately, the direct health risk from imbibing New Zealand drinking water is minimal. The WHO has set the recommended maximum level of nitrate in drinking water to be 11.3 mgl^{-1} N as nitrate or 50 mgl^{-1} NO_3^-. Above this level, the risks of infantile methemoglobinemia, or baby-blue syndrome, increases.[7] Although a rare and not well understood condition, nitrate has been implicated as a co-factor, potentially due to the conversion of nitrate to nitrite within the body. Approximately 5% of the monitored sites have nitrate levels above this limit; however, the likelihood that these sites are used for drinking water is relatively low.

The chemistry of nitrate

Nitrogen is an essential nutrient in plant growth with nitrate, NO_3^-, and ammonium, NH_4^+ the most biologically

accessible forms of nitrogen. However, natural sources of bioavailable nitrogen are limited, and pre-industrial era agriculture methods required the implementation of crop rotation and the recycling of crop residue and livestock waste. The ability to convert dinitrogen to ammonia by the Haber-Bosch process is considered one of the greatest accomplishments in modern history as it enabled the intensification of agriculture production, leading to the population explosion seen in the past century.[8] Nitrate cannot be synthesised directly from dinitrogen, but is made indirectly from the oxidation of ammonia. The most common nitrogen-based fertilisers are ammonium nitrate, urea (another compound obtained from ammonia) and other related salts.[9]



Scheme 1. Simplified version of the nitrogen cycle ["org-N" = organic nitrogen]

The nitrogen produced by livestock, primarily from urine, is in the form of "organic" nitrogen (org-N, Scheme 1) that undergoes mineralisation by soil bacteria to form ammonia and eventually nitrate (by autotrophic bacteria). Ammonium has a relatively high residence time within soil as its positive charge allows it to bind to the negative charge of clay minerals. Nitrates, in contrast, are essentially resistant to immobilisation; as such, they are responsible for nitrogen loss from land and subsequent transport into groundwater.

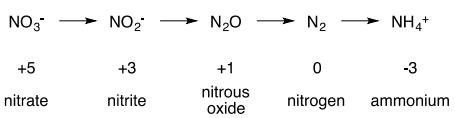
The 2013 Sustainable Dairying Water Accord set out good farming practices to help keep New Zealand's freshwater system clean.[10] Five key areas were targeted in the accord: riparian management, nutrient management, effluent management, water use management and conversions of new dairy farms. While not specifically aiming at nitrate management, these accords should help reduce the amount of nitrates leaching into the waterways. On-farm management includes planting trees on erosion-prone land, protecting streams with either plants or riparian strips to absorb inorganic pollutants or fencing to prevent animals defecating and urinating directly in the waterways and the restoration of wetlands to help absorb and process excess nitrogen and phosphorus waste. Vogeler *et al.* have reported on the impact of some nitrate mitigating strategies over a three-year period.[11]

A chemical approach that showed significant promise was the application of nitrate inhibitors directly to farmland, which prevents the bacterial conversion of ammonium to nitrates. The most common inhibitor is dicyandiamide (DCD), which is relatively cheap, highly water soluble and decomposes completely in the soil to carbon dioxide and ammonium.[12] Although it inhibits the conversion of ammonium to nitrite, it does not affect other heterotrophs within the soil.[12b] When applied to pastures alongside fertilisers, nitrogen leaching was reduced by up to 30% in some areas.[11,13] However, after traces of DCD were found in milk, its use was quickly abandoned.[14]

Once in groundwater, nitrate mitigation strategies involve either microbial or chemical methods. Nitrate removal via the former method involves denitrification beds and walls. In New Zealand, these beds are made up of woodchips or sawdust to provide carbon as an energy source for the microbes.[15] Under optimal conditions, these beds are effective at converting nitrates to dinitrogen with only a minimal amount of N_2O (the product of incomplete reduction) released into the atmosphere. However, these beds can be sensitive to temperature and oxygen levels and there is concern about pollution swapping; that is, while nitrate is consumed, measurable amounts of nitrous oxide, carbon dioxide and methane are released.[1,15b,16]

Chemical approaches to nitrate removal can be classified into two groups: chemical reduction of nitrate to ammonium (or ammonia depending upon the pH), dinitrogen gas and other oxidation states of nitrogen, or separation of nitrate via ion exchange, reverse osmosis or adsorption.[17] The latter method is beyond the scope of this review and the reader is directed to excellent sources elsewhere.[17-18] Chemical reduction methods include passive reduction in which a nitrate reacts directly with a reducing agent, reduction by dihydrogen gas in the presence of a catalyst,[19] and electrochemical reduction where electrons are provided via some form of electrical current, generally at a noble metal surface.[20] While the latter two methods would be applicable in an industrial setting, their suitability for *in situ* remediation is not clear.

There are four main N-containing products in the chemical reduction of nitrate: nitrite (NO_2^-), nitrous oxide gas (N_2O), dinitrogen gas (N_2) and ammonium ion (Scheme 2). Of these, nitrous oxide, a greenhouse gas, and nitrite, toxic to humans at >22 mg/kg body weight, are the most problematic. Although ammonium is less mobile in groundwater than nitrate, it can undergo nitrification back to nitrate. As such, unless ammonium is trapped, its formation only temporarily removes nitrogen from ground water. The holy grail of nitrate reduction is dinitrogen gas, and considerable research is underway to determine how to best favour this product.



Scheme 2. Common nitrate reduction products and their oxidation states

Chemical methods of nitrate reduction

Nitrates can undergo spontaneous reduction by a variety of different reducing agents ranging from main group

metal hydrides to zero valent metals. For the chemical reduction of nitrate prior to 2000, please see the excellent review by Fanning.[21] In acidic media, the standard reduction potential of nitrate (N^{5+}) to ammonium (N^{3-}) is 0.875 V, and nitrate to dinitrogen gas (N^0) is 1.246 V. In basic media, the standard reduction potential for both reactions is more thermoneutral at -0.01 and 0.43 V, respectively. Thus, a wide range of zero valent metals should be able to reduce nitrate in acidic media, providing the kinetics for the reaction are feasible.

Two general classifications of ZVM will be defined for the purposes of this review: macrosize (referred to as ZVM) and nanosize (nZVM). The former include powder and chips, and are generally commercially available, although some modification of the surface might be needed to optimise their reactivity. nZVMs are less than 100 nm in size and are generally not commercially available on a bulk scale.

Macrosize ZVM

The most common nitrate-reducing ZVM is zero valent iron (ZVI).[22] With a standard reduction potential of -0.037 V or -0.771 V in acidic or basic media, respectively, it is perfectly set up to react with nitrate. The first reported use of ZVI in nitrate reduction was in 1964.[23] However, it wasn't until the 1990s that further research was performed in this area. Although referred to as ZVI, an iron oxide (Fe_3O_4) surface layer is usually present on top of the iron(0) core. Despite its facile reactivity, the drawback to ZVI is that the major N-containing by-product upon reacting with nitrate is ammonium, generally accounting for >90% of nitrogen-containing products. ZVI reacts with nitrate in a two-step process to form first nitrite, a two electron process, which then reacts with further ZVI to form ammonium, a six electron process (Eqs. 1 & 2).

$$Fe^0_{(s)} + NO_3^- + 2\,H^+ \longrightarrow Fe^{2+} + NO_2^- + H_2O \qquad \text{(Eq. 1)}$$

$$3\,Fe^0_{(s)} + NO_2^- + 8\,H^+ \longrightarrow 3\,Fe^{2+} + NH_4^+ + 2\,H_2O \qquad \text{(Eq. 2)}$$

Although the mechanism for nitrate reduction has yet to be fully elucidated, the effect of surface area, oxide coating and pH have been the focus of several studies.[24] The fastest nitrate reduction rates by ZVI occur at low pH.[25] However, the direct reaction of nitrate with iron increases the pH of the solution, which is further compounded by the increase of pH from the corrosion of Fe(0). Although buffering the solutions to neutral pH lowers the reduction rate,[26] these buffered solutions are more representative of the environmental conditions for remediation. The requirement for a low pH on a facile reaction rate can be overcome if additional ferrous (Fe^{2+}) ions are added to the solution.[27] Although ferrous ions do not react with nitrate, it is assumed that these ions activate the iron oxide surface to allow rapid electron transfer from the iron(0) core. The mechanism for this activation process is not known.

The surface of ZVI has a significant effect on the reaction rate. When aged ZVI surfaces were activated with dihydrogen gas at 400 °C to remove the oxide coating, the nitrate reduction rate increased by a factor of 4.7.[28] A relationship between surface area and reaction rate has also been observed.[29] Several methods, including acid washing and ultrasonication, have been utilised to increase the surface area of ZVI. The nitrate reduction rate was enhanced when carried out at low pH in an ultrasonic bath.[30]

Other metals, notably magnesium, aluminium and zinc, have also been utilised to reduce nitrate. Aluminium reduces nitrate to form ammonium,[31] and its use has been investigated as a viable method for the removal of nitrates in some types of nuclear waste.[21] Magnesium also reacts with nitrate; however, in contrast to iron and aluminium, only 60% of the nitrogen is converted to ammonium, and the 35% of nitrogen unaccounted for is assumed to be lost as either nitric / nitrous oxide or dinitrogen gas.[32] As with iron, the reduction of nitrate with magnesium was found to be a function of surface area and solution pH. In a separate study, nitrogen gas and nitrite could be formed as the major nitrogen by-product when the magnesium reduction of nitrate occurred in an ultrasonic bath.[33] The ultrasonic bath was shown to decrease the oxide coating on the magnesium surface, allowing for direct interaction between the zero-valent magnesium and nitrate.

Metallic zinc can reduce nitrate to ammonia via nitrite.[34] Although the overall nitrate loss is faster than iron-based systems, a significant build-up of nitrite is found in the reaction mixture as the conversion of nitrite to ammonia is rate limiting. One group was able to take advantage of this by reacting the nitrite with sulfamic acid, which released dinitrogen gas and sulfuric acid.[35]

Bimetallic systems have been employed to encourage the formation of dinitrogen gas over ammonia. Noble metal surfaces have been found to favour the former pathway; however, they require an electron source as their reduction potential is closer to that of nitrate.[18b] Although primarily studied with regards to the electrochemical reduction of nitrate, depositing these metals onto good electron donors such as iron, aluminium or zinc has led to encouraging results. For instance, when iron powder was coated with 5% palladium, the selectivity towards production of dinitrogen gas increased.[36] When catalytic amounts of Pd and Cu were deposited on an activated iron surface, dinitrogen gas selectivity increased to 30%, with ammonium accounting for 60% of the nitrogen-containing products.[37] Other catalytic systems, including Au/Cu and Pt/Cu, also increased the selectivity towards dinitrogen gas over iron alone. The reactivity of zero valent aluminium can also be altered. Addition of catalytic amounts of both Pd and Cu onto aluminium resulted in 34% selectivity towards dinitrogen gas. When zinc is used as the electron donor, selectivity towards dinitrogen gas was greater than 60% when catalytic amounts of palladium were deposited on the surface.[34]

To be useful in environmental remediation, ZVMs must be reactive under a multitude of conditions, including in the presence of various ions such as chloride, phosphate, sulfate and carbonate. Unfortunately, the results in these "field" tests vary and are at times contradictory.

One investigation found that the nitrate reduction rate by ZVI decreased in the presence of chloride, sulfate or phosphate, and the extent of this decrease was proportional to the strength of surface complexation by these ions.[38] However, ZVI was successfully used to simultaneously remove nitrate, hydrogen peroxide and phosphate from semiconductor wastewaters.[39] Although this last study was able to remediate hydrogen peroxide, this latter molecule has also been reported to effectively inhibit nitrate reduction by ZVI.[40]

When ZVI was used in conjunction with clay minerals such as bentonite, fuller's earth or biotite, nitrate removal from ground water was found to be faster than from lab-simulated ground water.[41] This was attributed to the formation of green rust in ground water, which is known to be effective at reducing nitrate.[42] Good results in removing nitrate and ammonia from livestock wastewater were obtained when ZVI was used in conjunction with ammonia absorbants such as filtralite, sepiolite (both of which are clay minerals) or granular activated carbon.[43] Although these results are promising, it should be noted that the livestock wastewater underwent extensive pretreatment such as filtration to remove particles and coagulation to remove viscous materials that might coat, and thus mask, the activity of ZVI. Phosphate, nitrates and some pesticides were removed from synthetic agriculture drainage water by ZVI coated with an iron/sulfur layer.[44] This latter result is encouraging as it indicates that ZVI can be used as a multi-faceted approach for removing several different types of contaminants.

Nano-sized ZVM

In order to maximise the surface area of ZVM, and hence its reactivity, nano-size ZVM (nZVM) have been examined for use in nitrate remediation. Zero-valent iron nanoparticles (nZVI) in environmental remediation was first described in the late 1990's.[45] Several field trials utilising nZVI have led to encouraging results, although limitations have also been noted.[24,46] The first published report of nZVI for nitrate remediation was in 2000 in which complete denitrification with no pH control was noted.[47] Since then, the field of nZVI for nitrate remediation has subsequently expanded.[48] Although several studies have focused on different methods for the synthesis of nZVI, the standard method involves reduction of ferric or ferrous ions with borohydride salts under anaerobic conditions (Eq. 3).[48] Other synthetic methods include hydrogen reduction of goethite,[49] electrochemical methods,[50] and arc discharge.[51] Borohydride reduction of iron salts was also performed in the presence of dispersion agents such as polyglycol (PEG) to reduce aggregation and produce particles with a uniform size and shape distribution.[52] Further studies have investigated the effect of addition rate of reductant on particle size, with smaller particles (approx. 10 nm) obtained when the iron reduction occurred over a short time with a high reductant concentration.[53] Consistent with other findings correlating reactivity with particle size (and hence surface area), the smaller particles were able to reduce nitrate faster than larger particles.

$$4\,Fe^{2+} + BH_4^- + 3\,H_2O \longrightarrow 4\,Fe^0_{(s)} + H_3BO_3 + 7\,H^+ \quad \text{(Eq. 3)}$$

$$8\,Fe^{3+} + 3\,BH_4^- + 9\,H_2O \longrightarrow 8\,Fe^0_{(s)} + 3\,H_3BO_3 + 21\,H^+ \quad \text{(Eq. 4)}$$

Stability and storability are two concerns regarding the viability of nZVI in environment remediation. The nanoparticles are usually synthesised in aqueous solutions so they generally have an iron oxide coating. Although this core-shell model exists for macro-size ZVM, the oxide shell in the nanoparticles is relatively thinner.[54] Studies on the aging properties of these nanoparticles reveal that the method in which they are exposed to air will help determine their stability. Slow oxidation essentially creates a protective magnetite (Fe_3O_4) layer.[55] Rapid oxidation results in the formation of other iron oxide compositions, including wustite (FeO), hematite (a-Fe_2O_3) and maghemite (g-Fe_2O_3), all of which are less conductive than magnetite.

The enhanced reactivity of nZVI doped with catalytic amounts of other transition metals has been noted since nZVI was first used in environmental remediation.[45] As with macro-size ZVI, the doping of nZVI with other metals might result in favouring dinitrogen gas over ammonium. When copper was deposited on nZVI to form nZVI-Cu (0.5, 5, 10 and 20 %), the resulting bimetallic particles exhibited a higher nitrate reduction rate than nZVI alone, with nZVI-Cu (5%) exhibiting the fastest reduction rate.[56] nZVI-Cu was also found to be more reactive towards nitrate than nZVI doped with either palladium or platinum. However, a significant build-up of nitrite was found with nZVI-Cu, presumably due to the inability of copper to directly reduce nitrite. When nZVI was generated in the presence of nickel ions (1, 5, 10 and 20% doping), the rate of nitrate reduction was an order of magnitude faster than nZVI alone (with 5% Ni content), even at neutral pH.[57] Although ammonium accounts for >90% of the product, this result reveals the catalytic role of nickel in nitrate reduction. Nitrate reduction is also enhanced in the presence of cadmium.[58] While this metal is far from ideal for environmental remediation, it does highlight the potential of synergistic behaviour between contaminants.

Supported nZVI

One of the problems of nZVI is its propensity to aggregate due to its high van der Waals force and magnetism, leading to decreased nitrate reduction rate.[59] In addition, nZVI has been shown to bioaccumulate in medaka fish larvae, resulting in 40% mortality at concentrations greater than 50 mgl^{-1} nZVI. To minimise potential bioaccumulation, overcome the aggregation problems, increase the handling of nZVI and potentially widen its potential use, nZVI has been synthesised in the presence of a variety of different supports (noted as support@nZVI). These include micro-scale exfoliated graphite,[60] carboxymethyl cellulose (CMC),[61] ion exchange resins (ICR),[62] biopolymer calcium alginate beads,[63] kaolinite,[64] nano-size silica ($nSiO_2$),[65] polystyrene beads,[66] pillared clay,[67] titanium dioxide (1%TiO_2-sol),[68] and graphene oxide.[69] Of these, only a handful have been investigated for their ability to reduce nitrate. [61-64,68]

In many cases, supporting the nZVI led to faster reactivity than nZVI alone, presumably due to minimising the agglomeration of the iron nanoparticles.[67] For example, CMC-supported nZVI (CMC@nZVI) led to faster nitrate reduction, with the ratio of dinitrogen gas to ammonium changing upon the addition of Cu/Pd catalysts to the system. Encouragingly, nitrate reduction by CMC@nZVI occurred even in the presence of 6% NaCl as a source of chloride ions.[61] The enhanced nitrate reduction rate observed for ICR@nZVI was attributed to the increased surface area of the supported versus unsupported nZVI as measured using BET analysis.[62] Although the SEM of Ca-alginate@nZVI revealed the nZVI had agglomerated on the alginate surface, the nitrate reduction rate was faster for Ca-alginate@nZVI than pure nZVI.[63]

Using supported nZVI also changes the product distribution. For instance, when nZVI was supported on titanium dioxide (TiO_2@nZVI), the amount of dinitrogen gas increased from less than 10% dinitrogen gas with nZVI alone to 40% with nZVI@TiO_2.[68] Note that these reactions occurred under UV light to promote the photochemical reaction of TiO_2. Although the nZVI was formally supported on 1% TIO_2-sol, the actual ratio of TiO_2:Fe ranged from 1:2 to 1:20, indicating that titanium acts as a catalyst in nitrate reduction.

Although supported bimetallic systems have not been the focus of many studies investigating nitrate reduction, some results are encouraging. For instance, the reduction of nitrate by kaolinite@nZVI-Ni(5%) was dependent upon the concentration of copper(II) in solution.[64a] In the absence of copper, only 27% of nitrate was reduced in 15 minutes; however, in the presence of copper, over 42% of nitrate was reduced. This system was found to be effective at removing lead and nitrate from electroplating waste water.[64b]

The reactivity of unsupported non-iron nanoparticles, i.e. cobalt and nickel, in nitrate reduction was only found viable when these metals were supported on graphene oxide.[69] The authors of this study attribute this enhanced reactivity to the increased dispersion of the nanoparticles on the graphene oxide surface.

nZVI and microbes

The microbial reduction of nitrate in the presence of nZVI was examined to determine if nZVI could enhance the activity of the microbes.[70] In this study, nitrate reduction occurred in the presence of several other ions that were present to support bacterial growth. This is in contrast to most other studies in which only nitrate and a few known ions were present in the media. Without bacteria, nitrate reduction was slow, with a half-life of approximately five days. However, in the presence of bacteria, nitrate reduction was more facile, and complete reduction occurred within three days. The abiotic reduction of nitrate was presumably due to the reaction of the iron nanoparticles with nitrate, although their reactivity was severely depressed by the surrounding media. In the microbial reduction of nitrate, the nZVI acted as an electron donor, potentially via the controlled release of Fe^{2+}, which the bacteria can utilise directly. However, care must be taken as Fe^{2+} can be toxic to some denitrifying bacteria.[71] It has also been observed the ammonium production can be muted by denitrifying bacteria, where nitrate nitrogen is presumably incorporated into the growing biomass.[72] When hydrogenotrophic bacteria were added to nZVI, the rate of nitrate reduction decreased by 59 – 91%. The authors speculated that this could be due to the bacteria enhancing the rate of reaction between nZVI and water. This results in the observed Fe(O)OH surface which inhibits electron transfer out of the Fe(0) core.[73]

Applications of nZVI

In order for nZVI particles to be a viable technology for the removal of nitrates, they must maintain their reactivity in the presence of other ions. The evidence for inhibitory/enhancement effects of ions is far from complete, with less than a handful of studies examining the effect of ions on nitrate reduction. One study showed that common cations such as Cu^{2+}, Fe^{2+} and Fe^{3+}, as well as some common anions such as citrate, acetate, sulfate, chloride and carbonate enhanced the activity of nZI in nitrate reduction whereas phosphate had inhibitory effects.[74] In contrast, other studies show inhibitory effects of sulfate ions on nZVI-Pd reduction of pentachlorophenol, yet activity is maintained in the presence of Cu^{2+}, Ni^{2+} or Fe^{3+}.[75] It was postulated that the sulfate poisons the palladium surface; however, only a catalytic amount of palladium is present (0.054 wt%) and the control experiment with pure nZVI was unfortunately not presented in the study to allow a reliable conclusion to be made. Both sulfate and phosphate inhibited the Ni-nZVI reduction of TCE; interestingly, TCE reduction was also inhibited by nitrate, presumably due to competing reductive pathways.[76] The effects of ions appears to be concentration dependent with high concentrations of sodium chloride inhibiting the nitrate reducing ability of nZVI.[77] There is some oxygen sensitivity as dissolved oxygen reacts with the iron surface to form Fe(O)OH. Although this will transform to generate magnetite (Fe_2O_3) which is conductive towards electron transfer, it was found that adding Fe^{2+} improves the nitrate reduction capability of nZVI, even in the presence of dissolved oxygen.[78]

Another concern is the interaction of nZVI with natural organic matter (NOM) such as humic acid (HA). Although not examined specifically for nitrate reduction, the effect of HA on the nZVI reduction of TCE showed inhibition, although some quinoid NOM model systems such as juglone and anthroquinone disulfonate actually enhance the reduction rate.[79] HA was found to inhibit the removal of zinc and nickel ions, but not chromium(VI).[80] This result is intriguing as zinc and nickel ions are not chemically reduced by nZVI, but are removed via surface-mediated complexation; however, chromium(VI) is chemically reduced by nZVI via surface-mediated reductive precipitation. This indicates that although HA blocks the absorption of ions to the nZVI surface, it is not inhibiting electron transfer. Studies on the reduction of TCE in the presence of HA and nZVI-Ni revealed an inverse relationship between HA concentration and TCE reduction rate.[81]

Conclusions

Although a cost-benefit analysis is required for using ZVI and nZVI in the remediation of nitrates in New Zealand,[2a] this technology shows clear promise and should be considered in areas where other methods have failed.

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Alexander Lawrence Johnson BSc, MSc, PhD, FNZIC (1931 — 2015)

Alexander L. Johnson was born in Gisborne on 13 October 1931 and passed away in Lititz, Pennsylvania, USA on 16 November 2015 aged 84.

After completing his early education in Gisborne between 1937 and 1949, Alex moved to Wellington to attend Victoria University, earning a BSc in chemistry in 1953. One year later he earned his MSc degree with First Class Honours. Working under the direction of Professor Stanley N. Slater, his thesis dealt with the naturally occurring plant toxins picrotoxin and tutin. For the following five years he taught at Rongotai College in Wellington.

In August 1960 Alex emigrated to the USA as a Fulbright scholar to pursue a PhD at the University of Rochester. Under the direction of Professor Dean Stanley Tarbell he researched the chemistry of the antibiotic spectinomycin. In 1963 he began a 30-year career in chemical research at DuPont and then DuPont-Merck Pharmaceuticals at the Experimental Station in Wilmington, Delaware. His research involved a broad series of projects on exploratory heterocyclic medicinal and plant growth regulatory efforts. He was the group manager of the cardiovascular research group that discovered cozaar (losartan), the first of a new class of blood pressure-regulating drugs.

At the time of his retirement in 1994 Alex was the Associate Director of Research at DuPont-Merck. He was also the author or co-author of 105 publications, 14 patents, a speaker at numerous scientific meetings, an Emeritus member of the American Chemical Society and a Fellow of the New Zealand Institute of Chemistry.

He is survived by his wife, Joan, three children and five grandchildren.

Joan E. Johnson MD

Shining synchrotron light on materials science in New Zealand

Bridget Ingham

Callaghan Innovation, P.O. Box 31310, Lower Hutt 5011
(email: *bridget.ingham@callaghaninnovation.govt.nz*)

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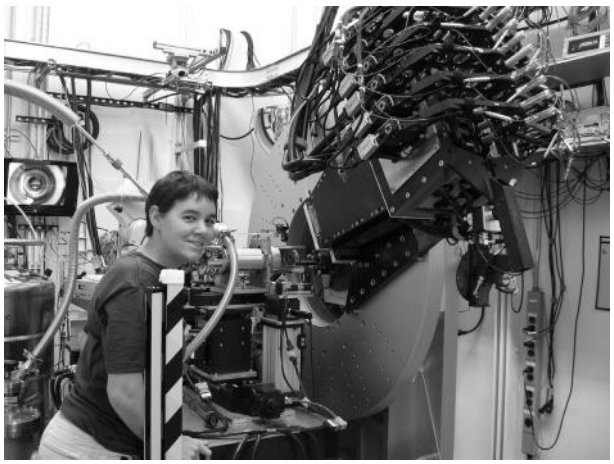

Dr Bridget Ingham is a Senior Research Scientist at Callaghan Innovation (formerly Industrial Research Ltd.). Following her PhD (physics, Victoria University of Wellington, 2005) she spent two years in a post-doctoral position at Imperial College London and the Stanford Synchrotron Radiation Lightsource, where she developed her current expertise in the use of synchrotron techniques for investigating nanomaterials, particularly X-ray diffraction, small-angle X-ray scattering and X-ray absorption spectroscopy.

Abstract

Synchrotron facilities produce bright beams of electromagnetic radiation from infrared to hard X-rays, which can be used for the characterisation of materials. This article describes the benefits of using synchrotron radiation, illustrated by way of four case studies: corrosion of steel, nanoparticle synthesis, thin oxide layers on metals, and calcium in milk. It also gives a brief history of New Zealand's involvement with the Australian Synchrotron, and outlines the current situation and potential future developments.

Introduction

Electromagnetic radiation is frequently used to obtain elemental, chemical, and structural information about molecules and materials. For example, infrared and Raman spectroscopy probe vibrational frequencies of chemical bonds; UV-visible absorption spectroscopy is used to determine electronic band gaps; X-ray diffraction (XRD) gives insights into crystallographic ordering. These techniques have advantages in that they are generally non-destructive and provide an ensemble average of the properties of the material.

Synchrotron radiation is produced when a charged particle, such as an electron, moving at relativistic speeds, is deflected. There are around 40 synchrotron facilities presently operating globally.[1] The first-generation synchrotron facilities developed as parasitic use of particle accelerators in the 1960s, following the first observation of synchrotron radiation in 1947.[2] Storage rings were developed in the late 1960s and 1970s to recirculate the electron stream, and form the basis of modern facility design. The second-generation period began in the early 1980s with the development of dedicated synchrotron storage ring facilities. A growing need for high brilliance, i.e. high flux with small beam size and low divergence, led to the development of third-generation sources from the mid-1990s to the present. These are designed to have a number of straight sections around the storage ring, into which 'insertion devices' can be installed. These devices include undulators and wigglers, which consist of periodic magnet structures that cause the electron beam to oscillate, resulting in a beam of radiation with much higher flux than can be produced using a standard bending magnet, as was used in previous generations.

Modern synchrotron facilities have several design elements in common. Electrons are produced in an electron gun and accelerated using a linear accelerator (or 'linac') into a booster ring, where their kinetic energy is increased further before injection into the storage ring. As the electrons travel around the ring, they release energy in the form of electromagnetic radiation tangential to every point where they are deflected (either by a bending magnet or an insertion device). Ports can be placed at these points to channel the synchrotron light towards an experimental station, called a 'beam line'. The energy lost by the electrons on each cycle is replaced through a radio frequency (RF) 'kick', from one or more RF cavities located on the storage ring.

The range of wavelengths produced at a particular beam line depends on the kinetic energy of the electrons in the storage ring and the strength of the magnetic field. While this article will focus on synchrotron X-ray applications, it is important to note that many synchrotron facilities operate beam lines spanning a wide range of the electromagnetic spectrum, from the infrared region to hard X-rays (100 keV). Since a facility can accommodate multiple beamlines, it is essentially a radiation 'tool box', offering a wide variety of techniques across a wide variety of wavelength ranges.

The principle benefit of synchrotron radiation, as has already been noted, is the extremely high flux. Laboratory X-ray sources offer brilliance values (flux per unit area

per solid angle, i.e. flux focused onto the sample) of 10^8 photons.s^{-1}.mm^{-2}.rad^{-2} for a standard sealed tube, and around an order of magnitude higher for a rotating anode; the brilliance of current state-of-the-art molten liquid jet anode sources can achieve up to 2.6×10^{10} photons.s^{-1}.mm^{-2}.rad^{-2},[3] which is approaching that of a second generation synchrotron source. A third-generation synchrotron beam line will typically have brilliance values of around 10^{16}-10^{20} photons.s^{-1}.mm^{-2}.rad^{-2}.[4] This high flux enables measurements to be made from samples that have a weak signal (for example X-ray fluorescence of trace elements, or X-ray diffraction of nanoparticles), and/or to collect data using much shorter measurement times than can be achieved using laboratory instruments. Some of the case studies in this article demonstrate how the short measurement times afforded by synchrotron radiation allow chemical processes to be followed in real-time. The synchrotron beam also has very low divergence, meaning that it can be focused to a very small spot on the sample. This enables X-ray imaging of samples to be performed, often combined with other techniques (absorption, fluorescence, diffraction, etc.). A third major benefit of synchrotron radiation is its tuneability: selecting the X-ray wavelength to obtain element-specific information about the structure of the material being studied.

Several case studies will now be presented to highlight these benefits.

Case studies

1. Corrosion of steel

The corrosion of steel due to the presence of carbon dioxide dissolved in the water phase is a major problem for the oil and gas industry. Iron carbonate ($FeCO_3$, siderite) often forms, and under certain conditions can act as a protective scale.[5,6] The corrosion mechanism can be studied using electrochemical methods. When these are combined with synchrotron XRD of the electrode surface, the electrochemical response can be related to the formation of a crystalline film, and the kinetics followed in real-time.[7-11]

Experiments were performed at the Powder Diffraction beamline at the Australian Synchrotron using a custom-built electrochemical cell, previously designed for *in situ* electrochemical studies of zinc oxide nanostructures.[12] This cell consisted of a heated reservoir approximately 50 mL in volume, which contained the electrolyte solution (0.5 M NaCl, saturated with CO_2 and pH adjusted to 6.8 with 1 M NaOH), into which a Pt counter electrode and Ag/AgCl microreference electrode were placed. The working electrode was a 1.5 mm diameter rod of the steel being studied, located at the base of the cell below the reservoir. X-rays were diffracted from the top surface of the rod, which was polished to 1 µm. The cell was tapered from the reservoir to the sample, so that at the sample position the electrolyte thickness (and therefore the X-ray beam path length through the solution) was 2 mm. This provided an acceptable compromise between reducing the solution scattering without grossly affecting the diffusion of solution ions. The X-ray beam energy was chosen to be 15 keV (λ = 0.82653 Å), and the beam size was 0.2 × 0.7 mm (vertical × horizontal). Diffraction patterns were collected in a continuous fashion using a VHR CCD detector positioned 93 mm from the sample, with an exposure time of 1 minute per image.

The diffraction patterns were radially averaged and the strongest peak from each crystallographic phase fitted. The area of the peak corresponds to the volume of diffracting material, and can be used as a measure of the film thickness (assuming the film has constant density). The XRD results gave insight into the electrochemical response in potentiostatic experiments performed on mild steel (Fig. 1).[7] The initial current density was constant for a period of around 30 minutes, which was termed the induction period. During this time the supersaturation was increasing up to a critical level required for crystallisation of $FeCO_3$, which was first observed at around 30 minutes. After this the current density started to rise. This was attributed to the formation of $FeCO_3$ causing local acidification of the solution, which accelerated the dissolution of the steel electrode. The current density reached a maximum after around 75 minutes and then decreased rapidly. The $FeCO_3$ growth curve reached a maximum slope at the same time that the current density reached its maximum value, and then plateaued. This plateau indicated the film growth had ceased due to passivation, which was also evident in that the final current density was lower than its initial value.

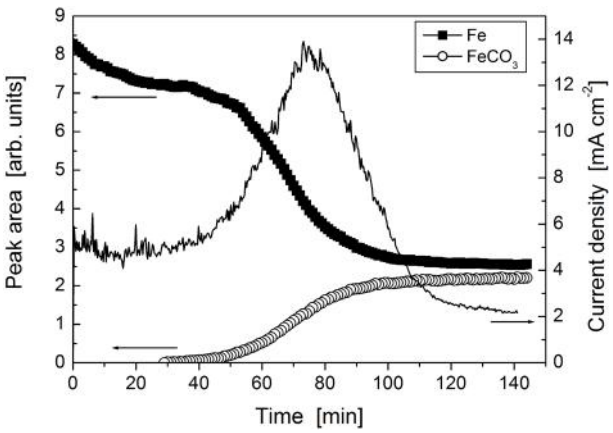

Fig. 1. Synchrotron X-ray diffraction (left-hand axis, symbols) and electrochemical current density (right-hand axis, line) response for the CO_2 corrosion of mild steel in 0.5 M NaCl at 80 °C under potentiostatic control (-500 mV vs. Ag/AgCl). Adapted from Ref. 7, Copyright (2012), with permission from Elsevier.

The effect of temperature in the formation of a protective scale was found to agree with earlier predictions.[6] Galvanostatic experiments on mild steel showed passivation behaviour for temperatures 80 °C or higher, while at temperatures below 80 °C no passivation was observed.[8] The film formation rate also increased with increasing temperature.

Adding other metal ions alters the supersaturation and consequently the growth kinetics. When Mg^{2+} was added to the solution, the formation of $FeCO_3$ was accelerated, as evidenced by both the XRD and electrochemical results.[7] $Fe_2(OH)_2CO_3$ was also observed at later times. Cr^{3+} added to the solution had a pronounced effect – just 10 µM was sufficient to compress the time scale by a fac-

tor of two.[9] Experiments were also performed on Cr-containing steels, which showed dramatically different behaviour compared to mild steel, despite having a similar microstructure: the current density peak was reduced in height, and in the XRD experiment crystalline $FeCO_3$ was observed earlier and grew more slowly.[9]

In addition to the emergence of diffraction rings of $FeCO_3$, it was noted that the initially smooth Fe diffraction ring became 'spottier' during the induction period.[8] Various statistical methods were used to quantify the development of the 'spottiness' throughout the experiment, and showed that this was most likely due to preferential dissolution of small grains, beginning as soon as the current was applied.[10,11] To test the hypothesis that the roughened surface caused by this dissolution is a prerequisite for $FeCO_3$ film formation, an experiment was carried out under the same solution conditions on an electrode that had been pre-roughened by abrading with emery paper. The rise in current density began straightaway, and a crystalline $FeCO_3$ film was observed at much shorter times.[11]

The effect of the steel microstructure was also explored, for both carbon steel and Cr-containing steel.[11] While there was little difference between ferritic/pearlitic and martensitic microstructures in the Cr-containing steel, the carbon steel with martensitic microstructure took three times as long to reach the current density peak than the carbon steel with ferritic/pearlitic microstructure. The induction time to the observation of crystalline $FeCO_3$ was longer, and the growth rate was slower.

Synchrotron experiments on this system have provided new insights into the corrosion and film formation mechanisms. Currently, work is underway using synchrotron grazing incidence small-angle X-ray scattering (GI-SAXS) to test a new hypothesis that the first stage of $FeCO_3$ film formation is via an amorphous precursor, which cannot be detected with XRD.[13]

2. Nanoparticle synthesis

Metallic nanoparticles have many potential applications in medicine,[14-17] high density data storage,[17-19] catalysis,[20-23] etc.[24] Their properties are highly size- and shape-dependent.[21] In solution synthesis of nanoparticles, the choice of surfactant can induce formation of particular shapes through preferential attachment to particular crystallographic planes.[25]

In situ synchrotron X-ray scattering has been used to study nanoparticle formation in non-aqueous solutions at elevated temperatures under reducing atmospheres.[26-28] These experiments used a custom-designed cell,[29] which consisted of a stainless steel body with a small cavity. X-ray transparent windows mounted on either side of the cavity allow scattering or diffraction patterns to be obtained in transmission geometry from the nanoparticles that form in solution. The X-ray path length through the solution was 1 mm. After assembling the cell, the solution (~0.1 ml) was injected into the cavity and a gas fitting attached. This allowed the cell to be flushed with hydrogen and sealed. It was then placed in a heating unit mounted on the synchrotron beam line. Experiments were performed at the Stanford Synchrotron Radiation Lightsource on beamlines 7-2 (XRD) and 1-4 and 4-2 (SAXS).

Experiments performed using the cell followed the synthesis of Pt nanoparticles up to reaction times of around 8 hours.[26] Two different solution conditions using different concentrations of Pt precursor were compared: one that was known to produce compact nanocubes, and one that was known to produce high surface area branched nanoparticles. The growth curves were obtained from the areas of the Pt diffraction peaks, which are proportional to the total volume of crystalline Pt (Fig. 2). While the low concentration experiment showed a monotonic increase in peak area, for the high concentration experiment the particle growth appeared to occur in four distinct stages. Transmission electron microscopy (TEM) images of nanoparticles extracted from the cell at times corresponding to each stage corroborated the synchrotron experiments, and together the results gave insight into the formation mechanism of the highly branched structures.

In the first stage (up to 100 minutes), the growth rate was very high, and compact cube-like particles were formed. From 100-180 minutes, the growth rate plateaued. During this stage the TEM images revealed that the cube-like particles appeared to continue to grow in size, but at the same time were being etched on their faces. This resulted in a net increase of crystalline volume that was close to zero. After 180 minutes the growth rate increased

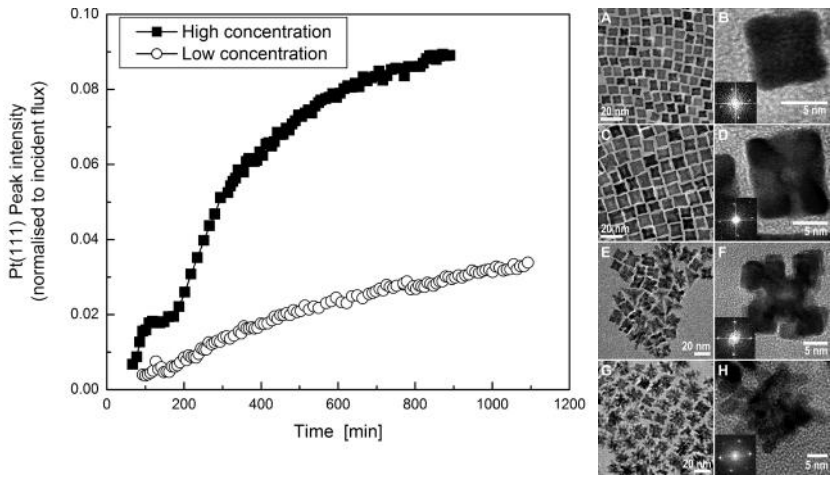

Fig. 2. In situ XRD study of Pt nanoparticle synthesis. (a) Pt(111) XRD peak area versus time; (b) TEM images of particles obtained from high-concentration reactions after (A, B) 75 min; (C, D) 120 min; (E, F) 240 min; (G, H) 500 min. Insets in B, D, F, and H show the fast Fourier transform of the respective images. Reprinted (adapted) with permission from Ref. 26. Copyright (2009) American Chemical Society.

again, up to 300 minutes where it tapered off. These two stages correspond to continued growth of the branched structures, until all of the Pt precursor was exhausted. SAXS data collected *in situ* showed a single population of scattering objects around 10 nm in size developed at early times, with a second population of smaller objects becoming evident later.[29] The second population corresponds to the formation of branches in the latter stages of particle formation. Branched Pd nanoparticles were also studied in the same cell using *in situ* XRD in a similar manner.[27]

An in-depth SAXS study was undertaken on Ni nanoparticles, using the same cell, exploring the effect of the nickel precursor:surfactant ratio.[28] As the relative amount of surfactant was increased, the resulting final particle size decreased. For a 1:1 ratio, the particles had a very narrow size distribution. The total volume versus time curves for the initial stages were fitted using a two-stage nucleation and autocatalytic growth model.[30] Interesting effects were observed at later times; in a number of experiments the particles were observed to start interacting with one another (as evidenced by the emergence of a structure factor peak, which was best fitted using a sticky hard sphere model).[28] It was hypothesised that at the onset of this behaviour, a critical number of particles had reached a size sufficient to render them ferromagnetic. This then caused magnetic attraction of the smaller, superparamagnetic particles in solution, resulting in the formation of aggregates.

These studies show how complementary information can be obtained from different synchrotron techniques, combined with electron microscopy, to reveal the underlying mechanisms driving nanoparticle size and shape. In the case of the Pt particles, previous TEM work had focused on the final product. It was assumed that the difference in the final shape was the result of a different nucleation mechanism for the high and low precursor cases. It was therefore a surprise to discover that the particles in both cases had the same initial cube-like shape. For Ni nanoparticles, the information afforded by the synchrotron SAXS experiments allows the reaction time to be chosen to obtain particles of a specific size, having a narrow size distribution, prior to the onset of ferromagnetism which results in the particles aggregating.

3. Thin oxide layers

Nearly all metals oxidise upon exposure to air, but the thickness and protectiveness of these oxide layers vary greatly depending on the material. For example, iron in moist air usually forms non-adherent Fe_2O_3, while stainless steel forms a protective oxide layer only a few nanometres thick. The structure of these oxide layers can be difficult to characterise due to the small volume of material and limited long-range order. X-ray absorption spectroscopy (XAS) can provide information about the valence and local co-ordination environment of an element of interest. Measurements on thin films can be performed by measuring the fluorescence intensity as the X-ray energy is scanned in the vicinity of an absorption edge (the requirement for variable X-ray energy means that these measurements can only be performed using synchrotron sources). An XAS study of the oxide layers formed on Fe-Cr alloys of various composition under electrochemical control showed a dramatic change in behaviour when the Cr content exceeded 18%.[31] Similar measurements were also performed on passive films formed on iron, where Fe_2O_3 was found to transform to Fe^{2+} and Fe_3O_4.[32] *In situ* XRD measurements of the passive film formed on iron revealed that it was around 4-5 nm thick and adopted a structure similar to Fe_3O_4, but with a high proportion of vacancies, antiphase boundaries and stacking faults.[33-35]

For nanoparticles, the presence of a surface oxide can greatly affect the particle structure and its physical properties. Some metals, such as palladium, have oxide layers that are as little as one atomic monolayer thick,[36] and are undetectable with X-ray diffraction – although the strain that they cause is evident.[37] X-ray absorption spectroscopy was used to directly detect the removal of this oxide layer by exposing a sample to a reducing gas (5% hydrogen in nitrogen) at ambient temperatures.[37]

Thin surface layers, including oxides, can also be probed using X-ray photoelectron spectroscopy, either by varying the angle[38] or, using a synchrotron, by varying the X-ray energy.[39] Both methods probe different escape depths for the emitted electron, and based on the known inelastic mean free path for electrons in the material, the ratio of bulk to surface signal can be modelled to extract the layer thickness.

4. Calcium in milk

As stated earlier, the tuneability of synchrotron radiation can be used to obtain structural information from materials according to a particular element of interest. A similar practise is frequently employed in neutron diffraction and scattering by matching neutron scattering cross-sections of various parts of the system (usually by mixing hydrogenated and deuterated solvents). In X-ray scattering, the atomic scattering factor changes slowly with energy except near an absorption edge, where resonant components arising from electronic transitions become significant. By measuring diffraction or scattering patterns at several X-ray energies in the vicinity of an absorption edge of the element of interest, one can separate the scattering features arising from structures containing the element of interest.[40-42]

A recent example of the technique is a study that conclusively identified the scattering features arising from colloidal calcium phosphate (CCP) nanoparticles in milk.[43] Despite the widespread use of milk as a calcium-rich food source, there is still significant controversy in the literature over the structure of the casein micelle, in which most of the calcium is located.[44,45] Literature reports using small-angle neutron and small-angle X-ray scattering disagree on the position of the CCP scattering feature.[46-49] Resonant soft X-ray scattering[50,51] was performed at the Advanced Light Source, Berkeley, on beamline 11.0.1.2, to probe the CCP particles in liquid milk at the calcium L_2/L_3 absorption edge (~350 eV).[43] A prominent peak emerged as the energy was scanned through the calcium

edge (Fig. 3), having a similar position to that previously observed in neutron scattering where the solvent (water) was contrast-matched to protein.[48] In contrast, the prominent feature in SAXS that is normally attributed to CCP, showed no change with energy in this range. The results gave credence to a recent hypothesis that the SAXS feature is instead due to protein inhomogeneities within the casein micelle.[46,47]

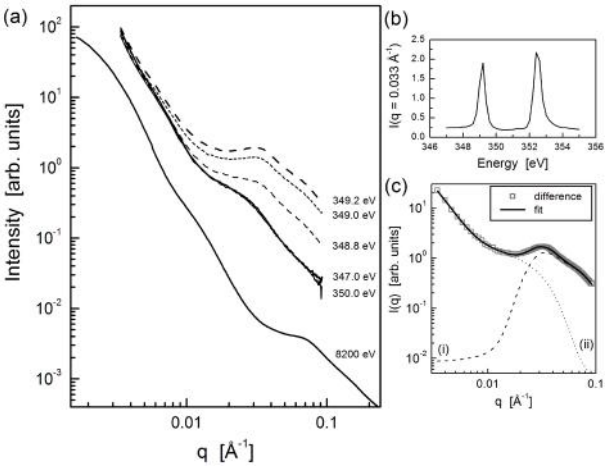

Fig. 3. (a) Resonant soft X-ray scattering of liquid milk at energies near the Ca L_2-edge, as labelled, shown together with typical SAXS of liquid milk collected at 8200 eV (for which the intensity scale has been translated). (b) Intensity variation at fixed q (0.033 Å^{-1}) corresponding to the peak in the curves in (a), as a function of incident X-ray energy. (c) Fit to a difference plot of I(349.2 eV) - I(350 eV) using two levels, to describe the CCP particle scattering (curve i) and the casein micelle scattering (curve ii). Adapted from Ref. 43 with permission from The Royal Society of Chemistry.

New Zealand synchrotron access

The use of synchrotron facilities by New Zealand researchers has greatly increased since the commissioning of the Australian Synchrotron[52] in 2007, and the concurrent establishment of the New Zealand Synchrotron Group.[53] The New Zealand Government and several institutions (Auckland, Massey, Waikato, Victoria, Canterbury and Otago universities, GNS Science and Callaghan Innovation) currently contribute to operational funding to ensure that New Zealand researchers enjoy a guaranteed level of access. Beamtime proposals are submitted to the Australian Synchrotron three times per year. Applicants are typically notified within three months, and experiments are conducted between four and six months from the submission deadline date. The New Zealand Synchrotron Group manages beamtime allocations and travel funding entitlements for New Zealand-based researchers.[53]

The Australian Synchrotron currently has ten operational beamlines available for general user access: imaging and medical, infrared microspectroscopy, terahertz/far-infrared spectroscopy, macromolecular crystallography (two beamlines), powder diffraction, small- and wide-angle X-ray scattering, soft X-ray spectroscopy, X-ray absorption spectroscopy and X-ray fluorescence microscopy.[52] On 7 December 2015 the Australian Federal Government announced an AU$520 million investment in the Australian Synchrotron over the next ten years for operating funding.[54] The Australian Synchrotron has been scoping the next stage of beamline development since 2010, pending the securing of operational funding.[55] With the recent investment announcement, plans are underway to secure funding for capital development from various sources, and the construction of new beamlines will begin in the near future. The proposed new beamlines to be built are: advanced diffraction and scattering, biological small-angle scattering, micro-computed tomography, medium energy X-ray absorption spectroscopy, high performance macromolecular crystallography, high coherence nanoprobe, and micro materials characterisation.[56]

Readers who are interested in applying the synchrotron techniques discussed in this article to their own research, or who wish to discuss a possible beam time application, are invited to contact the author via email.

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A chemist's perspective of enzyme inhibitor design

Peter C Tyler

Ferrier Research Institute, Victoria University of Wellington, P O Box 33436, Petone
(email: *peter.tyler@vuw.ac.nz*)

Keywords*: N-ribosyltransferases, iminoribitols, transition state analogues, enzyme inhibitors*

Introduction

Enzymes have been a source of fascination for many scientists over the years. The enzyme-induced catalytic rate enhancement of a reaction by many orders of magnitude is astounding, and understanding the exact details of enzyme catalysis continues to occupy the careers of prominent scientists. Many enzymes are pharmaceutical targets because of their biological contexts and more than 300 enzyme inhibitors are FDA-approved (US Food and Drug Administration) drugs.[1] Enzyme inhibitor development in the pharmaceutical industry has generally followed the well-established pathway of screening for leads, lead optimisation and/or structure-based inhibitor design employing protein crystallography. This has resulted in useful inhibitors as exemplified in drugs on the market [such as allopurinol (gout), gemcitabine (cancer) and abacavir (AIDS)]. However, a more sophisticated and technically difficult approach involves the fundamental analysis of enzyme kinetics leading to the experimental determination of the transition state of an enzyme-catalysed reaction. The transition state is the highest energy point on a reaction coordinate with a lifetime in the femtosecond range. To try to determine the structure of something with such a fleeting existence might seem foolhardy, but a combination of kinetic isotope measurements and quantum chemical calculations can be used to derive an electrostatic potential energy surface map of the transition state.[2-5] This map delivers bond angles and bond lengths within the electrostatic surface and provides a stereoelectronic blueprint for inhibitor design. The perfect transition state analogue inhibitor would bind more tightly than the substrate to its cognate enzyme by a factor equivalent to the catalytic rate enhancement imposed by the enzyme. Since enzymatic rate enhancements can approach a factor of 10^{20} there is potential for exceptionally powerful inhibitors using this approach.[6] However, a transition state will generally involve partial bond orders and/or partial charges, so a perfect transition state mimic will not be possible. In the design of transition state analogues the intent is to capture as many important features of the transition state as possible in a stable molecule.

We have exemplified this approach with several enzymes over a number of years. All the enzymes are *N*-ribosyltransferases which have optimal properties for this strategy. They involve reactions at carbon where there is (at least) a partial change from sp^3 towards sp^2 character at the transition state with cationic charge development. The capture of these distinguishing features in stable molecules has provided some exceptional inhibitors. The inhibitor-design blueprint provided by an electrostatic potential energy surface map of the transition state lends itself to chemical invention for the design and synthesis of transition state analogues. This process as applied to a number of enzymes has generated some surprising results.

Purine nucleoside phosphorylase (PNP)

The human PNP enzyme is a salvage enzyme and catalyses the phosphorolysis of nucleosides inosine, guanosine and their 2´-deoxy analogues to the respective purine and sugar 1-phosphates. A lack of enzyme function leads to elevated nucleoside substrate concentrations in the blood and to a consequent build-up of 2´-deoxyguanosine triphosphate in T-cells.[7] The biological result is a lack of T-cell function[8] which could be beneficial in such cases of undesired T-cell proliferation as in T-cell cancers, tissue transplant rejection and autoimmune disease. Alternatively, blocking purine salvage would potentially lower levels of uric acid in the blood and provide a treatment for gout. Uric acid is the metabolic end point for purines.

Determination of the transition states of the bovine and human PNPs demonstrated that, surprisingly, they were significantly different, even though they share 87% sequence homology and share 100% of amino acids in the active site making contacts with substrate.[9-11] The bovine PNP catalysed phosphorolysis of inosine has a dissociative transition state with some retained bond order between the ribose and hypoxanthine so that the ribose is a partial cation. For human PNP, the transition state is fully dissociative with a fully developed ribocation and no bond order with the hypoxanthine or the phosphate (Fig. 1). These design templates provide for different compounds as optimal inhibitors for the two enzymes. Immucillin-H **1** (Forodesine) is a close mimic of the bovine PNP transition state while DADMe-Immucillin-H **2** (Ulodesine) better mimicks the human enzyme (Fig. 2). They are powerful low pM inhibitors of both enzymes, but discrimination is evident based on transition state mimicry. Forodesine inhibits the clonal expansion and

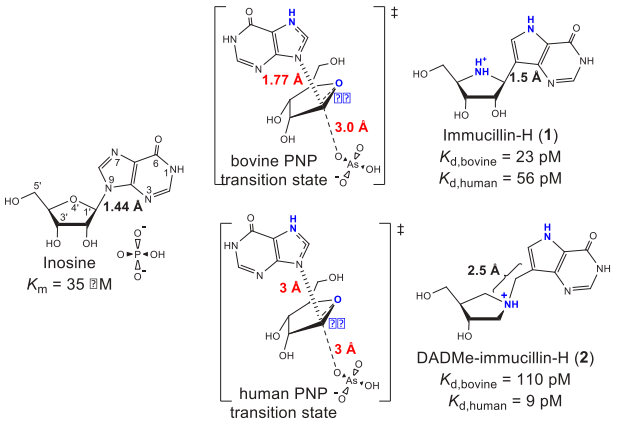

Fig. 1. Transition states for bovine and human PNPs. The inosine reactant binds to PNPs with a K_m of 35 µM. Bovine PNP has an early dissociative transition state while that of human PNP is S_N1 with a fully formed ribocation. Immucillin-H and DADMe-Immucillin-H mimic these respective transition states and show powerful, preferential binding.

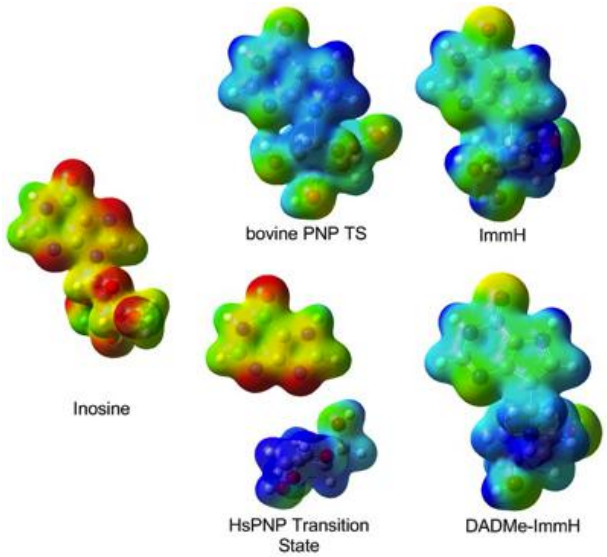

Fig. 2. Electrostatic potential maps of reactant, transition states for bovine and human PNPs and the transition state analogues shown in Fig. 1.

proliferation of human T-cells and is in clinical trials for T-cell leukemia.[12-14] Ulodesine has demonstrated efficacy at lowering blood uric acid levels in a phase II trial for gout.[15] These compounds attest to the potency attainable with transition state analogue inhibitors, further exemplified by the biological consequence that a single oral dose of **2** inhibits the enzyme for the lifetime of the cell.[16] PNP was a target for several pharmaceutical companies prior to our interest but standard structure-based design protocols led to inhibitors with inadequate potency and a phase III failure.[17]

The success of achieving two low pM inhibitors for PNP was very satisfactory and it seemed hardly likely that other more active inhibitors could be discovered. However, as chemists we always like to fiddle – and to see if we can improve things. A number of analogues of Immucillin-H **1** had been synthesised to explore the structure-activity relationships but, not surprisingly, none were more potent.[18] In particular, the methylene bridged analogue **3** which might be expected to better mimic the fully dissociated human PNP transition state is ~5000 times less active while **4** is also less active. Clearly these compounds are unable to adopt an optimum spatial arrangement for tight binding. The ribocation mimics in **1** and **2** are significantly different suggesting there is scope for variation in the aza-sugar. We explored the synthesis and testing of some acyclic aza-C-nucleoside derivatives with the idea that more flexible compounds might be better able to access the correct spatial orientation for tight binding to the protein (Fig. 3).[19] Initial results were not encouraging as **5 – 9** displayed poor affinity compared to **1** and **2**. Thinking that the entropic penalty of binding more flexible inhibitors to the protein might be confounding us, we explored other cyclic aza-sugar mimics. The azetidine **10** showed promising activity, and attempts were made to synthesise the corresponding aziridine **11**. However, it proved to be unstable under the conditions of synthesis and an acyclic derivative was isolated which was surprisingly active as a PNP inhibitor. After synthesising all the optical and stereoisomers of this compound, DATMe-Immucillin-H **12** was found to be another exceptional inhibitor of human PNP.[19] Furthermore, another survey of possible acyclic ribocation mimics brought to light SerMe-Immucillin-H **13**, a simple achiral molecule which is a 5.2 pM inhibitor of human PNP. The four low pM inhibitors discovered, **1**, **2**, **12** and **13** are quite different in their ribocation mimic moieties, yet x-ray crystal structures of protein-bound inhibitors has shown that they all occupy the active site and make the same (and expected) contacts with active site amino acids.[20] Clearly, inhibitor design based on an electrostatic potential energy surface map of the transition state doesn't result in a single optimum inhibitor. There are multiple options for compounds that capture significant proportions of the transition state binding energy and there appears to be plenty of scope for chemical invention in designing novel structures and realising powerful inhibitors.

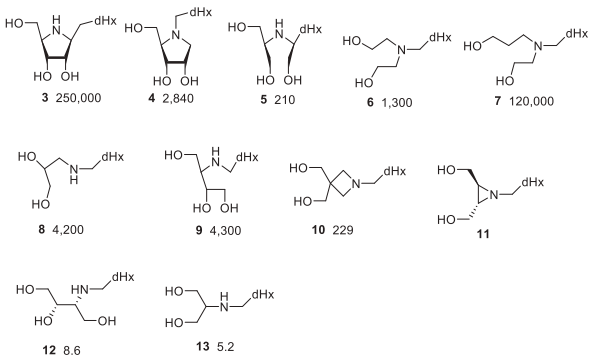

Fig 3. Structural analogues of **1** and **2** with their equilibrium dissociation inhibition constants against human PNP in pM. Abbreviations: dHx, 9-deazahypoxanthin-9-yl.

Thermodynamics

Assessment of the thermodynamics of binding of inhibitors **1**, **2**, **12** and **13** to human PNP showed, not surprisingly with the ion-pair interactions involved, that all had a strong positive enthalpic contribution to the binding energy.[21] However, the compound with the strongest enthalpy of binding (Imm-H **1**) was the weakest inhibitor. It is likely that binding of **1** to PNP induces protein rigidity with the consequent observed entropic penalty and that flexible inhibitors such as **12** and **13** result in more

flexible inhibitor-PNP complexes with a smaller entropic penalties and more potent binding.

Conclusions

Knowledge of an enzyme transition state structure allows for the design and synthesis of exceptionally powerful inhibitors. While the transition state might appear very prescriptive for inhibitor design, surprising structural diversity has been observed in potent transition state analogue inhibitors.

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NZIC Archives

For some years NZIC Council has been mulling over what to do with a filing cabinet full of archives that have been stored at Massey University. Last year I agreed, somewhat reluctantly, to take possession of these and to make an electronic copy of the records.

The first two drawers of the filing cabinet contain the membership application forms dating back to the start of the Institute. I am currently recording name, date joined, and place of work in an Excel file.

From 160 entries processed so far the things that strike me are:

The majority of members were employed by what must have been a myriad of small and large companies that existed in New Zealand in the 1930s and 40s each having chemistry input. The Dominion Laboratory was a big player, but also fertiliser works, dairy, rubber products, Eveready Batteries to name a few. Not surprisingly the emphasis is on the farming sector.

There was a strict criteria in place for membership. Nomination by a Branch, recommendation by two existing members, a record of university papers passed. There are a number of applications that were initially declined.

The ratio of academics to industrial chemists is pretty much the reverse of today's membership.

Richard Rendle (rendle@xtra.co.nz)

Article

Synthesis and application of polar phosphine ligands in Pd-catalysed reactions

Vivien L. van Zyl,[1] Alfred Muller,[1] D. Bradley G. Williams[1,2*]

[1]Department of Chemistry, University of Johannesburg, P.O. Box 524, Auckland Park, 2006, South Africa, [2]Ferrier Research Institute, Victoria University of Wellington, 69 Gracefield Rd, Lower Hutt, 5010 (email: *Bradley.williams@vuw.ac.nz)*

Keywords: *palladium, ionic liquid, catalyst, ligand*

Photo credit: Victoria University of Wellington Image Services

Bradley Williams spent two years as a postdoctoral fellow at Imperial College, London, after which he joined the University of Johannesburg (UJ) to start his academic career. He founded the highly successful Research Centre for Synthesis and Catalysis at the UJ, and performed many functions at the UJ as Professor of Chemistry, Deputy Head of Department: Chemistry, Chair of the Faculty of Science Higher Degrees Committee, and consultant to the petrochemical and pharmaceutical industries. In 2011 he was lured to Callaghan Innovation in Wellington, where he soon became Group Manager of Integrated Bioactive Technologies, a mixed group of scientists and engineers working to assist the food processing and nutraceutical sector in New Zealand, after which he joined the Ferrier Research Institute at Victoria University of Wellington as Professor and Senior Principal Scientist. The research interests of this Fellow of the NZIC span organic synthesis, homogeneous catalysis and analytical chemistry. For his research outputs and consulting work with the petrochemical industry, he was awarded the 2014 NZIC-Shimadzu prize for Industrial and Applied Chemistry. This paper, co-authored by collaborators from the UJ, is an example of his efforts towards improved catalysed organic transformations.

Abstract

A new range of polar imidazolium and phosphate-containing ligands was synthesised from readily available starting materials in high yielding multi-step transformations. These ligands were used to generate Pd catalysts for Suzuki and Heck C-C coupling reactions in organic and organic/aqueous media. The catalysts were stable to the formation of Pd black, a form of degradation that frequently befalls Pd catalysts.

Introduction

The primary role of ligands in the context of homogeneous catalysis is to modify the metal in question towards stability, activity, selectivity to product, isolation, recycling, etc. The role that ligands play in determining many of the features of metal-based catalysts has led to a prolific number and wide variety of ligands being prepared.[1] While heterogeneous catalysts are readily recovered and reused,[2] homogeneous catalysts suffer a persistent disadvantage because of the difficulties associated with recovering and recycling them. Polar phosphine ligands assist the recovery of catalysts in several possible ways. Firstly, if the ligands are sufficiently polar, they may be extracted into an aqueous phase post-reaction, having been held in the organic phase during the reaction.[3] Secondly, they may be held in an altogether separate phase, which may be aqueous or another non-miscible phase such as, for example, an ionic liquid.[4] Such biphasic systems facilitate the recovery and reuse of catalysts,[5] a pertinent example being the Rhône-Poulenc process. Here, a Rh catalyst is used in a biphasic medium (aqueous phase and organic product) to convert lower alkenes into higher value aldehydes and alcohols.[6] Triphenylphosphine trisulfonate is the ligand,[6] and it imparts to the catalyst a level of water solubility which reduces leaching of the Rh into the organic reaction product to very low levels. Polar ligands also assist the move towards more benign solvent systems, even if recovery of the catalyst is not under consideration, because aqueous or ionic liquid-based solvents can be employed.[7] It was an objective of the present study to investigate the synthesis, and application in catalysis, of different P-type ligands with the polarity being derived from phosphate-containing and imidazolium-containing moieties. These ligands would be assessed in Pd-catalysed C-C bond-forming Heck[8] and Suzuki[9] reactions in polar organic, organic aqueous and ionic liquid systems, and benchmarked against ligand-free counterparts.

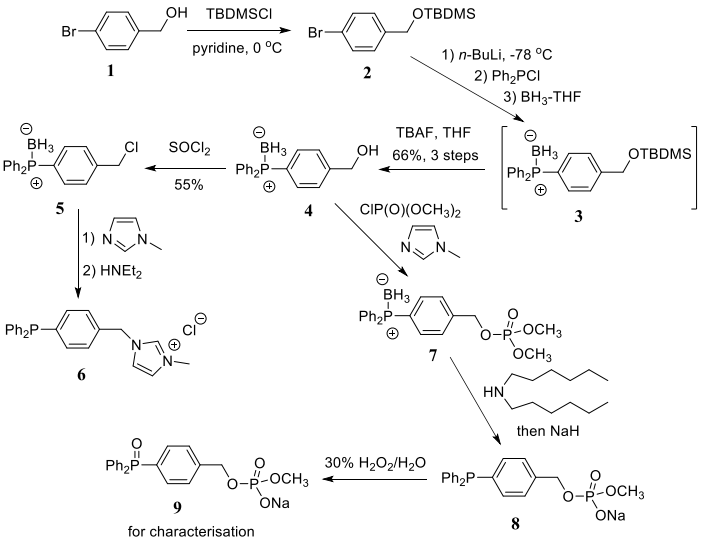
Results and discussion

The synthesis of these ligands rested on multi-step sequences which converted suitable starting materials into more complex derivative structures, making use of Ph_2PCl and Ph_2PH as sources of the P atom. These two substrates are useful as electrophiles and nucleophiles, respectively. In the case of Ph_2PCl as substrate, a nucleophile may attack the P atom, ejecting chloride to form a new P-C bond. In the latter, the P-H is deprotonated thereby converting it into a nucleophile suitable for reactions with, for example, α,β-unsaturated esters. In all cases, the products of these reactions were transformed into polar entities.

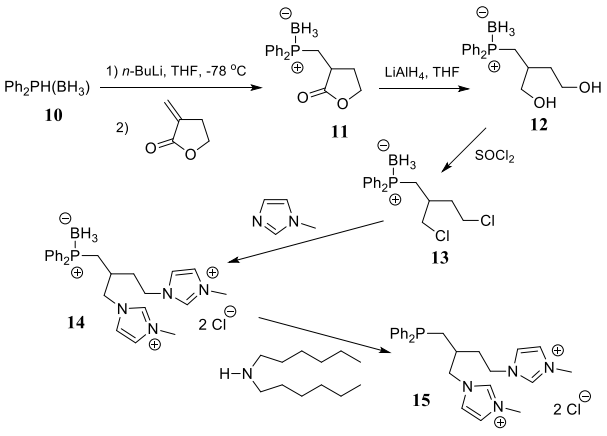
4-Bromobenzyl alcohol (**1**) was protected as its silyl ether **2** (Scheme 1), and the resulting product was subjected to lithium-halogen exchange with *n*-butyllithium.[10] Reaction of the lithiated intermediate with Ph_2PCl, and P-protection of the reaction product with BH_3-THF, afforded the triphenylphosphine derivative **3**. If the P-atom was unprotected during the conversion of the benzyl alcohol into its corresponding chloride under the action of thionyl chloride (see below), the P atom was oxidised into its unwanted P(O) derivative. Unmasking of the OH group by the action of tetra-*n*-butylammonium fluoride on **3** furnished benzyl alcohol **4** in 66% overall yield from **1**, after column chromatography on silica gel. A two proton singlet at 4.72 ppm in the ^{1}H NMR spectrum of the product was consistent with the anticipated benzyl alcohol CH_2 group. This product afforded the anticipated broad doublet signal at 20.8 ppm (J = 61.3 Hz) in the ^{31}P NMR spectrum thereof, accompanied by a range of doublet signals in the aromatic region of the ^{13}C NMR spectrum of the compound, caused by P-C coupling over a number of bonds. Uneventful conversion of the benzyl alcohol into its chloride analogue **5** under the action of thionyl chloride and reaction of **5** with excess *N*-methylimidazole at 100 °C, followed by P-deprotection with neat diethylamine,[11] afforded the desired imidazolium-containing phosphine **6** in a yield of 60% from **5**. The free phosphine and the diethylamine-borane complex were readily separated by extraction with DCM and water: the phosphine was soluble in the organic phase while the amine-borane complex was soluble in the aqueous phase. Compound **6** produced diagnostic signals for the imidazolium moiety in the ^{1}H NMR and ^{13}C NMR spectra thereof, accompanied by a sharp singlet at –5.1 ppm in its ^{31}P NMR spectrum, which provided evidence for deprotection of the P atom. Alternatively, benzyl alcohol **4** could be allowed to react with dimethyl chlorophosphate (CAUTION! This substance is highly toxic and requires special handling techniques.) to convert it into phosphate **7**. Deprotection of the P atom and partial hydrolysis of the phosphate ester of **7** with neat dihexylamine, followed by cation exchange with NaH, afforded the corresponding sodium phosphate **8**, which was characterised as its phosphine oxide **9**. In this instance, dihexylamine was chosen for the P deprotection step because the ligand would be soluble in the aqueous layer and it was desirable for the amine-borane complex to be soluble in the organic phase. The ^{1}H NMR spectrum of the P=O product **9** showed a characteristic two proton doublet at 4.88 ppm ($J_{H,P}$ = 8.2 Hz) and a three proton doublet at 3.56 ppm ($J_{H,P}$ = 9.5 Hz), while the ^{31}P NMR spectrum thereof showed two sharp singlet signals at 31.7 ppm (P(O)) and 1.1 ppm (OPO).

In a second approach to polar phosphines, diphenylphosphine-borane **10** was lithiated by reaction with *n*-butyllithium and the lithium phosphide was allowed to react with α-methylene-γ-butyrolactone in a Michael-type reaction to produce adduct **11** (Scheme 2). The lactone was readily reduced to the corresponding diol by reaction thereof with $LiAlH_4$ to produce the desired product **12** in a yield of 85%. Reaction of the diol with thionyl chloride followed by treatment of the dichloro intermediate **13** with *N*-methylimidazole at elevated temperature produced bisimidazolium chloride **14**. The P atom was released immediately prior to the catalysis by treatment of the product with dihexylamine to deliver free phosphine **15**. Diol **12** was also allowed to react with dimethyl chlorophosphate (CAUTION! This substance is highly toxic and requires special handling techniques), the product of which was deprotected, partially hydrolysed and subjected to cation exchange to produce the water soluble bisphosphate **17** (76% from **12**), which was characterised as its P=O derivative **18** (Scheme 3).

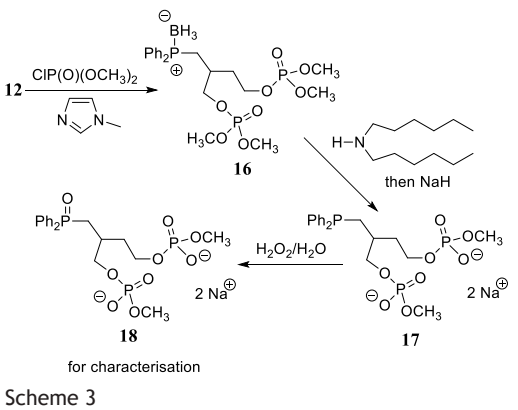
The ligands were then employed in Pd-catalysed Heck and Suzuki reactions (Scheme 4) as set out in Table 1.



Scheme 1



Scheme 2



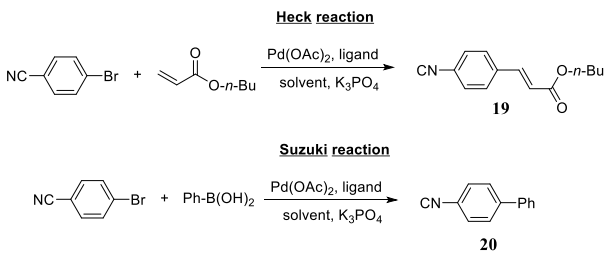
Scheme 3

Reactions were performed in organic medium and in organic/aqueous medium, and the catalysts were benchmarked against baseline systems which were devoid of ligands. In all instances, the ligands produced catalysts that were stable and from which no Pd black was formed. It is clear from the results that the ligands produce catalysts that are consistently good for the Heck and Suzuki reactions performed in DMF but that the Heck reactions performed in DMF/H_2O did not fare so well. In contrast, the catalysts all performed well to mediate the Suzuki reaction in DMF/H_2O. It is quite possible that the difference in outcome is due to the polarity of the reaction partners. It is unlikely that the 4-bromobenzonitrile, used as a substrate for the oxidative addition step that initiates both the Heck and the Suzuki reaction, causes the difference. Rather, for the Heck reaction the nonpolar butyl acrylate is used as substrate while in the Suzuki reaction the polar phenylboronic acid is used as substrate. Presumably, it is the low solubility of the former that hampers the progress of the Heck reaction in the polar organic/aqueous binary solvent.

Table 1. Pd-catalysed Heck and Suzuki-reactions[a]

		Heck product **19**		Suzuki product **20**	
Entry	Ligand	DMF	DMF/H_2O	DMF	DMF/H_2O
1	–	10%	5%	55%	60%
2	**8**	65%	20%	73%	75%
3	**9**	72%	20%	75%	76%
4	**6**	67%	25%	74%	78%
5	**12**	72%	28%	77%	80%
6	**14**	76%	45%	86%	86%
7	**17**	75%	43%	75%	75%

[a]See Appendix (experimental details) for reaction conditions



Scheme 4

Additional Heck reactions were performed in ionic liquids (Table 2). As a general comment on the outcomes of the reactions, the catalysts constituted from the new ligands performed as well as or better than the triphenylphosphine benchmark reaction. The ionic liquid of choice was [bmim]BF_4 (see Table 2 footnote for a definition of the abbreviations for the ionic liquids), which is the most polar of the ionic liquids employed. While the [bmim] and [hmim] ionic liquids could conceivably form carbene structures with Pd, the [C8dmim] ionic liquid cannot because the 2-position is blocked. That there was little difference between the outcomes when using this ionic liquid and those where the 2-position is free, would point towards the notion that carbenes generated from the ionic liquids are not involved in the catalysis. The ligands demonstrate their real usefulness during recycling experiments, though. Firstly, no Pd black was noted for any of the new ligands, indicating that stable catalysts were formed. Secondly, NMR spectra of concentrates of the organic extracts (post reaction) failed to show the presence of the ligands, demonstrating minimal leaching thereof, along with the Pd, into the organic phase. Recharging the substrates to the ionic liquid phase, once the organic phase had been decanted, allowed the recyclability of the catalysts to be assessed, using [bmim]BF_4 as the model system. Here, the catalyst containing ligand **6** was recycled three times (total of four runs with the same catalyst). These runs afforded yields of the Heck products of 88, 83, 84 and 81%, respectively. The high level of repeatability of the runs when making use of the recycled catalyst indicates the retention of high levels of the catalyst in the ionic liquid phase and that it did not suffer degradation or inactivation.

Conclusions

Imidazolium and phosphate-containing phosphines, produced in good overall yield in several steps from readily accessible starting materials, form stable Pd catalysts that are capable of effecting C-C bond-forming reactions in polar organic and organic/aqueous mixed solvent systems. The outcomes of the reactions are less linked with the nature of the Pd-ligand system than they are with the solubility of the substrates. If the substrates are only slightly soluble in the organic/aqueous medium, then the reactions are plagued by low yields. The presence of the imidazolium or the phosphate groups clearly does not hamper the catalyst activity. Selected ligands were demonstrated to form stable and active catalysts in ionic liquids and recycling experiments revealed an ability to reuse the catalysts over several runs without loss of activity.

Acknowledgements

We thank the NRF, THRIP, University of Johannesburg, Victoria University of Wellington and Sasol for funding. DBGW is grateful to the New Zealand Institute of Chemistry and to Shimadzu for the 2014 prize for excellence in Industrial and Applied Chemistry.

Table 2. Pd-catalysed Heck reactions in ionic liquids[a]

Ligand	[bmim]BF_4	[hmim]BF_4	[C8dmim]BF_4	[bmim]$[NSO_2CF_3]_2$	[hmim]$[NSO_2CF_3]_2$	[C8py]$[NSO_2CF_3]_2$
TPP	74%	61%	58%	58%	48%	51%
6	88%	63%	68%	65%	48%	55%
15	81%	59%	56%	59%	45%	52%

[a] TPP = triphenylphosphine, bmim = 1-butyl-3-methylimidazolium, hmim = 1-hexyl-3-methylimidazolium, C8dmim = 2,3-dimethyl-1-octylimidazolium, C8py = *N*-octylpyridinium.

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Appendix - experimental details

Instruments

NMR spectra were recorded on a Varian Gemini 2000. Mass spectra were recorded on a Varian Spectrum 3400 CX instrument, while IR spectroscopy was performed on a Perkin Elmer 881 spectrometer. Accurate melting points determinations were acquired on a DSC822^e Mettler Toledo differential scanning calorimeter. Ligands were typically characterised as the borane adduct or the phosphine oxide due to oxidative instability of the free phosphine.

Silyl ether **2**[12]

4-Bromobenzyl alcohol (1.00 g, 5.35 mmol) and *t*-butyldimethylsilyl chloride (121 mg, 8.02 mmol, 1.50 equiv.) were added to pyridine (2 ml) and the solution was stirred at 45°C for 6 hours. Dichloromethane (20 ml) was added and the mixture extracted with water (3 × 5 ml). The organic layer was dried over anhydrous magnesium sulfate and filtered through a short column of silica gel to provide the silyl ether as a clear oil (90%).

R_f 0.18 (10:1 hexane/EtOAc); IR: ν_{max} ($CHCl_3$)/cm^{-1} 2960, 1474, 1087; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.43 (d, 2H, *J* = 8.7 Hz), 7.18 (d, 2H, *J* = 8.7 Hz), 4.67 (s, 2H), 0.92 (s, 9H), 0.08 (s, 6H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 140.4, 131.2, 127.6, 120.5, 64.3, 26.0, 18.4, –5.2; EIMS: *m/z* 301, 244, 169.

Phosphine benzyl alcohol **4**

n-BuLi (1.60 ml, 1.76 mmol, 1.1 M in hexane) was added in a drop-wise fashion to a solution of silyl ether **2** (530 mg, 1.76 mmol, 1.00 equiv.) in dry THF (45 ml) at –78°C. The reaction mixture was held at –60°C to –70°C for 1 hour, after which chlorodiphenyl phosphine (0.40 ml, 2.1 mmol, 1.2 equiv.) was added. The reaction mixture was allowed to warm to ambient temperature over six hours after which it was cooled to 0°C and THF-borane (1.76 mmol, 1 M) was added. The reaction was allowed to proceed at 0°C for 2 hours after which it was allowed to warm to room temperature and extracted with EtOAc (40 ml) and brine (3 × 5 ml). The organic solvent was removed under vacuum and the residue dissolved in THF (30 ml). Tetrabutylammonium fluoride trihydrate (461 mg, 1.76 mmol, 1.00 equiv.) was added and the solution stirred for 12 hours, after which it was diluted with EtOAc (60 ml) and extracted with saturated brine (3 × 5 ml). The organic layer was dried over anhydrous magnesium sulfate, the solvent removed *in vacuo* and the crude mixture was purified by column chromatography over silica gel (4:1 hexane/EtOAc) affording the P-borane product as a white solid (73%).

R_f 0.12 (4:1 hexane/EtOAc); mp: 100.5°C; IR: ν_{max} ($CHCl_3$)/cm^{-1} 3019, 2935, 2393, 1653; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.58–7.40 (m, 14H), 4.72 (s, 2H), 1.96 (br s, 1H), 0.83–1.61 (br m, 3H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 144.2, 133.3 (d, *J* = 10.0 Hz), 133.1(d, *J* = 9.6 Hz), 131.2 (d, *J* = 2.4 Hz), 129.1 (d, *J* = 57.6 Hz), 128.7 (d, *J* = 10.3 Hz), 128.1 (d, *J* = 58.2 Hz), 126.9 (d, *J* = 10.3 Hz), 64.6; ^{31}P NMR: (121 MHz, $CDCl_3$) d_p 20.8 (br d, *J* = 61.3 Hz); EIMS: *m/z* 305, 292, 183. Anal. Calcd. for $C_{19}H_{20}BOP$: C, 74.5; H, 6.6. Found C, 74.3; H, 6.5.

Phosphine chloride **5**

Benzyl alcohol **4** (1.00 g, 3.26 mmol) was dissolved in toluene (4 ml) and thionyl chloride (0.33 ml, 4.6 mmol, 1.4 equiv.) was added slowly. The mixture was heated under reflux for 2 hours after which it was extracted with dichloromethane (20 ml) and 10% aqueous $NaHCO_3$. The product was purified by flash column chromatography over silica gel (5:1 hexane/EtOAc) to produce the title compound as a white solid (55%).

R_f 0.72 (4:1 hexane/EtOAc); IR: ν_{max} ($CHCl_3$)/cm^{-1} 3009, 2389, 1437, 1107, 1060; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.61–7.41 (m, 14H), 4.58 (s, 1H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 140.6, 133.5 (d, *J* = 10.0 Hz), 133.1 (d, *J* = 9.6 Hz), 131.3 (d, *J* = 2.4 Hz), 129.5 (d, *J* = 58.0 Hz), 128.8 (d, *J* = 10.4 Hz), 128.74 (d, *J* = 10.8 Hz), 128.7 (d, *J* = 58.0 Hz), 45.4; ^{31}P NMR: (121 MHz, $CDCl_3$) d_p 21.1 (br d, *J* = 61.2 Hz); EIMS: *m/z* 312, 310, 275, 183. Anal. Calcd. for $C_{19}H_{19}BClP$: C, 70.3; H, 5.9. Found C, 70.4; H, 5.5.

Phosphine imidazolium chloride **6**

Benzyl chloride **5** (140 mg, 0.432 mmol) was dissolved in DMF (1.5 ml), after which *N*-methylimidazole (0.10 ml, 1.3 mmol, 20 equiv.) was added and the solution heated to 100°C for 24 hours. Excess *N*-methylimidazole was removed under vacuum and the product was treated with diethyl amine (1.4 ml) for 8 hours under reflux. The mixture was diluted with dichloromethane (30 ml) and extracted with water (3 × 10 ml). The organic layer was dried over anhydrous magnesium sulfate and the volatile component removed under reduced pressure. The product was isolated (60%) as a clear oil by column chromatography over silica gel (20% methanol in dichloromethane).

R_f 0.12 (10% methanol in DCM); IR: ν_{max} ($CHCl_3$)/cm^{-1} 3333, 2947, 1437, 1236, 1155 ; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 10.67 (s, 1H), 7.45–7.19 (m, 16H), 7.16 (s, 1H), 7.11 (s, 1H), 5.50 (s, 2H), 3.9 (s, 3H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 139.2 (d, *J* = 13.2 Hz), 137.8 (1C), 136.2 (d, *J* = 10.7 Hz), 134.3 (d, *J* = 19.2 Hz), 133.6 (d, *J* = 19.7 Hz), 128.9, 128.7 (d, *J* = 6.9 Hz) 128.5 (d, *J* = 7.2 Hz), 123.5, 121.8, 52.8, 36.6; ^{31}P NMR: (121 MHz, $CDCl_3$) d_p –5.13; EIMS: *m/z* 358, 342, 310, 183. Anal. Calcd. for $C_{23}H_{22}ClN2$: C, 70.3; H, 5.6; N, 7.1. Found C, 70.5; H, 5.6; N, 6.7.

Dimethylphosphate **7**

N-Methylimidazole (26 mg, 031 mmol, 1.4 equiv.) was added to a mixture of alcohol **4** (70 mg, 0.23 mmol) and chlorodimethylphosphate (40 mg, 0.28 mmol, 1.2 equiv. CAUTION! This substance is highly toxic and requires special handling techniques) in dichloromethane (10 ml) at ambient temperature. The mixture was stirred for 24 hours after which a saturated aqueous solution

of ammonium chloride (5 ml) was added. The aqueous layer was extracted with dichloromethane (3 × 5 ml) and the organic layer dried over anhydrous magnesium sulfate. Removal of the solvent and column chromatography (20% ethanol in EtOAc) afforded the product as a colourless oil (82%).

R_f 0.31 (20% ethanol in EtOAc); IR: ν_{max} ($CHCl_3$)/cm^{-1} 2995, 2952, 2410, 1267, 1061; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.43–7.23 (m, 14H), 4.92 (d, 2H, *J* = 7.8 Hz), 3.57 (m, 6H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 144.2, 133.3 (d, *J* = 10.0 Hz), 133.1(d, *J* = 9.6 Hz), 131.2 (d, *J* = 2.4 Hz), 129.1 (d, *J* = 57.6 Hz), 128.7 (d, *J* = 10.3 Hz), 128.1 (d, *J* = 58.2 Hz), 126.9 (d, *J* = 10.3 Hz), 64.6; ^{31}P NMR: (121 MHz, $CDCl_3$) d_P 22.0 (br m), 2.21; EIMS: *m/z* 401.

Phosphine oxide **9**

A solution of phosphate **7** (100 mg, 0.250 mmol) and dihexylamine (0.6 ml, 2.5 mmol, 10 equiv.) was heated at 50ºC for 12 hours after which the reaction mixture was extracted with water (10 ml) and 1:1 hexane/EtOAc (3 × 5 ml). For the cation exchange, the water was removed under vacuum and the residue dissolved in THF (2 ml) after which NaH (19 mg of a 60% dispersion in oil, 0.50 mmol, 2.0 equiv.) was added at 0ºC. For the oxidation step, H_2O_2 (1 ml of a 30% aqueous solution) was added and the mixture stirred at room temperature for 1 hour. The reaction mixture was allowed to stir at room temperature for 2 hours after which it was diluted with dichloromethane (10 ml) and extracted with water (3 × 5 ml). The aqueous layer was retained and removal of the water afforded the product as a white solid in a yield of 91%.

R_f 0.30 (33% ethanol in EtOAc); IR: ν_{max} (KBr)/cm^{-1} 2985, 2959, 1148, 1060; ^{1}H NMR: (300 MHz, D_2O) d_H 7.79–7.45 (m, 14H), 4.88 (d, 2H, *J* = 8.2 Hz), 3.56 (d, 3H, *J* = 9.5 Hz); ^{13}C NMR: (75 MHz, D_2O) d_C 140.1 (d, *J* = 2.4 Hz), 134.3 (d, *J* = 105.1 Hz), 133.4 (d, *J* = 10.2 Hz), 133.0 (d, *J* = 9.9 Hz), 132.8 (d, *J* = 2.7 Hz), 129.9 (d, *J* = 106.3 Hz), 129.1 (d, *J* = 12.0 Hz), 128.2 (d, *J* = 12.7 Hz), 66.0, 51.3; ^{31}P NMR: (121 Hz, D_2O) d_P 31.7, 1.1. Anal. Calcd. for $C_{20}H_{19}NaO_5P_2$: C, 56.6; H, 4.5. Found C, 56.7; H, 4.5.

Phosphine lactone **11**

n-BuLi (2.8 ml, 2.6 mmol, 0.9 M in hexane) was added to diphenylphosphine-borane (512 mg, 2.56 mmol, 1.00 equiv.) in THF (50 ml) at –78°C. The mixture was maintained for 2 hours at –60°C to –70°C after which α-methylene-γ-butyrolactone (0.24 ml, 2.8 mmol, 1.1 equiv.) was added in a drop-wise fashion and the mixture was allowed to warm to ambient temperature over 10 hours. Aqueous citric acid solution (5%, 10 ml) was added and the mixture stirred for 10 minutes. The use of citric acid avoided the formation of stable emulsions. The mixture was diluted with dichloromethane (20 ml) and extracted with water (3 × 5 ml). The organic layer was dried over anhydrous magnesium sulfate and the volatile component removed *in vacuo*. Column chromatography over silica gel (5:1 hexane/EtOAc) afforded a white solid product (74%).

R_f 0.12 (5:1 hexane/EtOAc); mp: 83.4 °C; IR: ν_{max} ($CHCl_3$)/cm^{-1} 3011, 2381, 1757, 1748. 1026; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.75–7.4 (m, 10H), 4.26 (t, 1H, *J* = 8.7 Hz), 4.07 (m, 1H), 3.10 (t, 1H, *J* = 12.9 Hz), 2.73 (m, 1H), 2.39 (m, 1H), 2.169 (m, 1H), 1.18 (m, 1H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 187.6 (d, *J* = 17.1 Hz), 132.1 (d, *J* = 9.1 Hz), 131.6, 128.5 (d, *J* = 3.3 Hz), 129.0 (d, *J* = 55.2 Hz), 66.6, 35.5, 30.4, 27.3 (d, *J* = 39 Hz); ^{31}P NMR: (121 MHz, $CDCl_3$) d_P 14.5 (br m); EIMS: *m/z* 299.

Phosphine diol **12**

Lactone **11** (119 mg, 0.400 mmol, 1.00 equiv.) in THF (1 ml) was slowly added to a suspension of $LiAlH_4$ (23 mg, 0.60 mmol, 1.5 equiv.) in THF (5 ml) such that a light reflux was maintained, after which the mixture was heated under reflux for 1 hour. Dichloromethane (10 ml) was added and the mixture extracted with water (3 × 5 ml). The product was isolated by flash chromatography over silica gel (1:1 hexane/EtOAc) to provide a clear oil (85%).

R_f 0.12 (1:1 hexane/EtOAc); IR: ν_{max} ($CHCl_3$)/cm^{-1} 3402, 3001, 2361, 1441, 1049; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.71–7.38 (m, 10H), 3.75 (m, 4H), 2.82 (s, 2H), 2.43 (m, 2H), 2.13 (m, 1H), 1.67 (m, 2H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 131.1 (d, *J* = 4.3 Hz), 132.0 (d, *J* = 4.6 Hz), 131.2 (t, *J* = 2.2 Hz), 129.7 (d, *J* = 55.3 Hz), 129.6 (d, *J* = 55.2 Hz), 128.8 (d, *J* = 9.8 Hz), 65.5 (d, *J* = 7.1 Hz), 60.1, 36.5 (d, *J* = 6.8 Hz), 34.5, 26.5 (d, *J* = 35.6 Hz); ^{31}P NMR: (121 MHz, $CDCl_3$) d_P 14.8 (br m); CIMS: *m/z* 301, 289, 200, 187. Anal. Calcd. for $C_{17}H_{24}BO_2P$: C, 67.6; H, 8.0. Found C, 67.6; H, 8.1.

Phosphine dichloride **13**

Thionyl chloride (0.50 ml, 6.8 mmol, 2.8 equiv.) was slowly added to diol **12** (728 mg, 2.44 mmol) in toluene (14 ml) and the mixture heated under reflux for 18 hours, after which it was diluted with dichloromethane DCM (30 ml) and extracted with 10% aqueous sodium bicarbonate (4 × 5 ml). The organic phase was dried over anhydrous magnesium sulfate, the solvents removed and the crude material purified by column chromatography over silica gel (6:1 hexane/EtOAc) to provide the desired product as a clear liquid in a yield of 68%.

R_f 0.3 (6:1 hexane/EtOAc); IR: ν_{max} ($CHCl_3$)/cm^{-1} 2930, 2490, 1438, 1217, 1104; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.71–7.45 (m, 10H), 3.51 (m, 4H), 2.69 (m, 2H), 2.34 (m, 1H), 1.9 (m, 2H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 132.7(d, *J* = 8.3Hz), 132.5 (d, *J* = 8.3 Hz), 132.29, 132.16, 129.23 (d, *J* = 10.3 Hz), 125.6 (d, *J* = 59 Hz), 125.0 (d, *J* = 58.0 Hz), 48.0, 41.56, 35.6 (d, *J* = 7.7 Hz), 32.5, 24.4 (d, *J* = 37.0 Hz); ^{31}P NMR: (121 MHz, $CDCl_3$) d_P 15.1 (br m); CIMS: *m/z* 327, 325.

Bis(imidazolium) dichloride **14**

A solution of dichloride **13** (90 mg, 0.27 mmol) in DMF (1.5 ml) was heated at 100ºC for 24 hours in the presence of *N*-methylimidazole (0.42 ml, 5.3 mmol, 20 equiv.). The volatile component was removed under vacuum and the degassed dichloromethane (10 ml) was added under argon. The mixture was extracted with degassed water (3 × 2 ml) and the solvent removed under reduced pressure. THF (2.0 ml) and THF-borane (0.27 ml, 0.27 mmol, 1.0 equiv.) were added at 0ºC and the solution was stirred for 2 hours. The mixture was diluted with dichloromethane (10 ml) and extracted with water (3 × 2 ml). Flash chromatography (20% methanol in dichloromethane) afforded the product as a clear oil (46%).

R_f 0.10 (20% methanol in dichloromethane); IR: ν_{max} ($CHCl_3$)/cm^{-1} 2929, 2388, 1770, 1203, 1024; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 9.35 (s, 2H), 7.75–7.43 (m, 10H), 7.03 (s, 2H), 6.90 (s, 2H), 4.23 (t, 2H, *J* = 9.0 Hz), 4.10 (m, 2H), 3.89 (s, 2H), 3.1 (t, 1H, *J* = 13.5 Hz), 2.56 (m, 1H), 2.54 (m, 1H), 1.97 (m, 1H), 1.62 (m, 1H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 140.4, 132.18 (d, *J* = 2.7 Hz), 132.02 (d, *J* = 2.9 Hz), 131.6, 129.1 (d, *J* = 10.1 Hz), 129.0 (d, *J* = 10.0 Hz), 125.4, 124.74 (d, *J* = 57.0 Hz), 124.68 (d, *J* = 55.5 Hz), 121.5, 66.6, 35.6, 35.5, 29.7, 27.3 (d, *J* = 39.0 Hz); ^{31}P NMR: (121 MHz, $CDCl_3$) d_P 16.2 (br m); CIMS: *m/z* 419, 391, 285, 269. Anal. Calcd. for $C_{25}H_{34}BCl_2N_4P$: C, 59.7; H, 6.8; N, 11.1. Found C, 60.0; H, 6.7; N, 11.4.

Phosphine-borane bisphosphate **16**

The same procedure employed to produce phosphate **7** was used here, where diol **12** (69 mg, 0.23 mmol) was used to synthesise the corresponding bisphosphate as a colourless oil (85%).

R_f 0.25 (20% ethanol in EtOAc); IR: ν_{max} ($CHCl_3$)/cm^{-1} 2991, 2368, 1244, 1043, 858; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.76–7.62 (m, 4H), 7.50–7.4.2 (m, 6H), 3.98 (m, 4H), 3.70 (d, 3H, *J* = 4.2 Hz), 3.69 (d, 3H, *J* = 1.5 Hz), 3.67 (d, 3H, *J* = 4.2 Hz), 3.66 (d, 3H, *J* = 1.2 Hz), 2.52 (m, 1H), 2.19 (m, 2H), 1.81 (m, 2H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C

132.1 (d, *J* = 9.2 Hz), 132.0 (d, *J* = 9.1 Hz), 131.4, 129.4 (d, *J* = 55.2 Hz), 129.1 (d, *J* = 54.9 Hz), 128.9 (d, *J* = 9.9 Hz), 66.0, 60.2, 54.4, 54.4, 54.3, 54.2, 32.6 (d, *J* = 6.6 Hz), 31.7 (d, *J* = 7.7 Hz), 27.3 (d, *J* = 35.6 Hz); ^{31}P NMR: (121 MHz, $CDCl_3$) d_p 15.0 (br m), 2.1, 1.9; EIMS: *m/z* 504, 199, 183. Anal. Calcd. for $C_{21}H_{34}BO_8P_3$: C, 48.7; H, 6.6. Found C, 48.9; H, 6.7.

Disodium phosphine oxide bisphosphate **18**

The procedure used to synthesise phosphate **9** was applied here, where bisphosphate **16** (100 mg, 0.200 mmol) was used to produce the disodium salt as a white solid (89%).

R_f 0.14 (67% ethanol in EtOAc); IR: ν_{max} (KBr)/cm^{-1} 2980, 1250, 1167, 856; ^{1}H NMR: (300 MHz, D_2O) d_H 7.85–7.70 (m, 4H), 7.52–7.38 (m, 6H), 3.93–3.79 (m, 4H), 3.44 (d, 6H, *J* = 4.5 Hz), 2.70–2.57 (m, 1H), 2.28–2.17 (m, 2H), 1.90–1.75 (m, 2H); ^{13}C NMR: (75 MHz, D_2O) d_C 133.8 (d, *J* = 13.1 Hz), 132.5 (d, *J* = 13.2 Hz), 131.8, 130.6 (d, *J* = 7.4 Hz), 130.5 (d, *J* = 7.4 Hz), 128.8 (d, *J* = 2.0 Hz), 128.6 (d, *J* = 2.0 Hz), 67.0, 63.2, 52.9, 32.3, 30.8, 28.6; ^{31}P NMR: (121 MHz, D_2O) d_p 23.3, 2.0, 1.8. Anal. Calcd. for $C_{19}H_{25}Na_2O_9P_3$: C, 42.6; H, 4.7. Found C, 43.0; H, 4.4.

General procedure for the deprotection of phosphine-borane complexes

The phosphine-borane complex (0.11 mmol) was dissolved in methanol (2 ml). Dihexylamine (0.102 ml, 0.440 mmol, 4.00 equiv.) was added and the reaction mixture heated to 80ºC for 10 hours. The solvent was removed under reduced pressure and the solid residue extracted with degassed 1:1 hexane/EtOAc (10 ml) and water (3 × 5 ml). The water was removed under vacuum and the free phosphine used immediately in the catalysis reactions.

General procedure for the Heck reaction

The relevant phosphine ligand (0.028 mmol, 0.10 equiv.) dissolved in DMF or 1:1 DMF/H_2O (2 ml) was stirred for 20 minutes in the presence of $Pd(OAc)_2$ (4 mg, 0.014 mmol, 0.05 equiv.). Triethylamine (0.040 ml, 0.28 mmol, 1.0 equiv.), butyl acrylate (0.039 ml, 0.28 mmol, 1.0 equiv.) and 4-bromobenzonitrile (51 mg, 0.28 ml, 1.0 equiv.) were added and the mixture heated at 110ºC for 24 hours. The volatile component was removed *in vacuo* and the residue dissolved in dichloromethane (10 ml) and extracted with water (3 × 2 ml). The organic layer was dried over anhydrous magnesium sulfate and the solvent was removed under reduced pressure. The residue was subjected to chromatography over silica gel (10:1 hexane/EtOAc) to provide the Heck product.

E-Butyl-3-(4-cyanophenyl)-2-propenoate (**19**)[13]

R_f 0.42 (10:1 hexane/EtOAc); IR: ν_{max} ($CHCl_3$)/cm^{-1} 2970, 2240, 1720, 1317; ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.67-7.57 (m, 5H), 6.49 (d, 1H, *J* = 16.2 Hz), 4.20 (t, 2H, *J* = 6.6 Hz), 1.72-1.63 (m, 2H), 1.48-1.35 (m, 2H), 0.94 (t, 3H, *J* = 7.5 Hz); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 166.2, 142.0, 138.7, 132.6, 128.3, 121.8, 118.3, 113.3, 64.8, 30.6, 19.1, 13.7; EIMS: *m/z* 230, 174.

General procedure for the Suzuki cross coupling reaction

The phosphine ligand (0.064 mmol, 0.10 equiv.) was dissolved in DMF or 1:1 DMF/H_2O (2 ml) and $Pd(OAc)_2$ (8 mg 0.03 mmol. 0.05 equiv.) was added after which the mixture was stirred for 2 minutes. Potassium phosphate (136 mg, 0.640 mmol, 1.0 equiv.), 4-bromobenzonitrile (116 mg, 0.64 mmol, 1.0 equiv.) and phenylboronic acid (78 mg, 0.64 mmol, 1.0 equiv.) were added and the mixture heated to 100ºC for 24 hours. Extraction with dichloromethane (10 ml) and water (3 × 3 ml), followed by drying of the organic layer over magnesium sulfate, removal of the solvent and column chromatography (10:1 hexane/EtOAc) afforded the Suzuki product.

4-Cyanobiphenyl (**20**)[14]

R_f 0.50 (10:1 hexane/EtOAc); ^{1}H NMR: (300 MHz, $CDCl_3$) d_H 7.57-7.42 (m, 4H), 7.38-7.28 (m, 5H); ^{13}C NMR: (75 MHz, $CDCl_3$) d_C 145.3, 138.8, 132.3, 128.9, 128.5, 127.5, 126.9, 118.7, 110.6.

Feature Series

Some Unremembered Chemists

A series of articles that explores the lives and work of selected chemists who have made a significant contribution to the advancement of the discipline, the profession and well-being of mankind, yet who are little remembered.

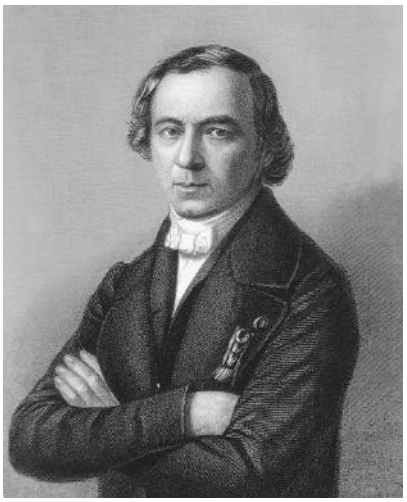
A trio of experimentalists: Jean-Baptiste André Dumas (1800-1884), Johan Gustav Christoffer Thorsager Kjeldahl (1849-1900) and Petrus Jacobus Kipp (1808–1864)

Brian Halton

School of Chemical & Physical Sciences, Victoria University, PO Box 600, Wellington 6140
(email: brian.halton@vuw.ac.nz)

The names of Kipp and Kjeldahl are likely recognised by the older chemists but not by those currently studying or those more recently graduated. Dumas will be the least recognised of this trio, but those with a biological bent could know that his recognition is closely related to that of Kjeldahl. Each of these distinguished chemists is known for the equipment and/or the methodology that he fashioned. They are covered individually below.

Jean-Baptiste-André Dumas (1800-1884)



André Dumas was born on July 14, 1800 in Alès, a commune in southern France some 40 km north-west of Nimes.[1] His parents, Jean Baptiste and Marie Madeleine (née Bastide) were cultured people, his father being the municipality Town Clerk.[2] The small town worked its coal mines that supported glassworks, brick yards, tile and earthen works, and lime kilns. The nearby Gardon river supplied iron pyrites for conversion into green vitriol [iron(II) sulfate or copperas] and antimony was mined for alloying uses. The boy received the best education available in the small town and attended the local college so that by the time he was 14 years old he was a good classical scholar and had acquired a fair knowledge of the natural sciences. Although his parents had a military career set for André, the downfall of the First Empire and the bloodshed of 1814-1815 led them to change their career choice and he was apprenticed to a local apothecary in the town where he carried out his first practical studies.[1] However, by the age of 16 he had decided to seek better opportunities elsewhere. When his parents agreed, he walked the more than 400 km to Geneva following the course of the Rhône, lodging with his relative M. Bérard once there. He gained employment in the apothecary of chemist and pharmacist Auguste Le Royer and studied pharmacy at the University, being taught chemistry by Gaspard de la Rive. Dumas was employed as superintendent of Le Royer's large chemical laboratory, which had been used for courses in applied chemistry and where he was free to use the limited facilities.[1] Some of his first experiments were aimed at measuring the volumes of atoms in solids and liquids by measuring their specific gravities by a method that was subsequently developed some 40 years later.[2]

During this period Dumas performed experiments for one of Geneva's most noted physicians, Jean-François Coindet. Coindet thought that the burnt sponge then used as a remedy for goitre might contain iodine. He referred this to Dumas who not only proved its presence in the sponge, but also indicated the best method of administering what proved to be almost a specific remedy. The discovery gave Dumas his first public recognition and for many years the manufacture of iodine preparations brought both wealth and reputation to the pharmacy of Le Royer. André's subsequent collaboration with Jean-Louis Prevost provided him with papers in the area of physiology and these attracted the attention of Alexander von Humboldt. This to the extent that upon visiting Geneva in 1822, von Humboldt went to Dumas' apartment and asked him to be his guide during his short stay in the area – but Humboldt did point out that he needed the service from 6 am till midnight each day![1] As a result of the informal discussion and excitement that von Humboldt engendered in Dumas, the 22-year old decided to move to Paris, then the accepted centre of scientific study.

So it was that in 1823 Dumas moved to Paris where his reputation had preceded him and where he was welcomed by the renowned scientists of the day (including Ampere, Bertholet, Gay-Lussac, Thenard, and Vauquelin).[1,2] Soon after his arrival he was appointed as a tutor in chemistry at the École Polytechnique and lecturer at the Athenæum, the institution charged with engendering a popular interest in science and literature. With geologist Brongniart and naturalist Audouin, Dumas founded the *Annales des sciences naturelles in 1824* and then some

two years later married Brongniart's sister Hermine at the church of *St-Thomas d'Aquin in Paris*. She was the eldest daughter of mineralogist Alexandre Brongniart, director of the royal porcelain works at Sèvres.[1-3]

On arrival in Paris in 1823, Dumas found that there was no laboratory instruction in chemistry and it was not until 1832 that he was able to establish one for research at his own expense.[1,2] Initially housed at the École Polytechnique, it moved to Rue Cuvier in 1839 where it was destroyed in the (February) revolution of 1848. The lab was small and only a few of the more advanced students were allowed entry; it was re-established at the Sorbonne in the French Second Republic and then in 1868 transferred to the École Centrale. In 1828 Dumas published the first of his eight volume *Traité de chimie appliquée aux arts*, the last appearing some 20 years later. The following year he was a co-founder of the École Centrale des Arts et Manufactures where he was Professor of Chemistry; he celebrated the 50th anniversary of the institution of his founding in 1878.[1-3] In 1832 Dumas succeeded Gay-Lussac as Professor at the Sorbonne, and then in 1835, Thenard at the École Polytechnique and in 1839 he accepted the chair at the École de Médicine. Thus, before aged 40, Dumas had held all the important chemistry chairs in Paris save that at the Collège de France.

Dumas's work is notable for its wide range rather than for its depth and insight.[1,2] His most original contributions came by adapting existing ideas rather than revolutionary breakthroughs. His practical interests led to numerous contributions to applied chemistry. These included the nature and properties of commercial glass, the materials used in thirteenth century frescoes, and the nature of the compounds of phosphorus and of lead tetroxide [$Pb(II)_2Pb(IV)O_4$]. Dumas made lasting contributions to the dyestuffs industry, analysing indigo and establishing the colourless and blue types. He was the first to show that picric acid was a derivative of phenol. Dumas made extensive studies of pharmaceuticals and established the correct formulae for several alkaloids. In January 1834, he read to the Académie des Sciences the results of research giving the correct molecular formulae of chloroform, bromoform, iodoform, and chloral for the first time. His most important problem concerned the organisation of chemical substances. He sought to devise comprehensive classification schemes for organic compounds and for the elements.

In 1826 Dumas developed a new method for directly measuring vapour densities, and indirectly (by calculation) the relative molecular weights of different substances in the gaseous state. His method, which had the merit of being both precise and simple, is still in use in analysis today. It was used by him to determine the molecular weights of phosphorus, arsenic, and boron. The procedure for a volatile liquid entails placing a small quantity (excess) of the substance in question into a tared vessel of known volume. The vessel is then heated in a water bath to a known temperature (above the sample boiling point) forcing all the air within the flask to be expelled through a tiny orifice and replaced by the vapour of the unknown substance. When no remaining liquid can be seen, the vessel is sealed, e.g. with a flame, then dried, cooled to room temperature and the condensed liquid weighed. By subtracting the tare of the vessel, the actual mass of the unknown vapour within the vessel (the weight of the residual liquid) is thus given. Assuming that the unknown compound obeys the ideal gas law (*PV = nRT*), the number of moles of the unknown compound, *n*, can be determined (P is the atmospheric pressure, V the measured volume of the vessel, T the absolute temperature of the boiling water bath, and R the ideal gas constant). By dividing the mass of the vapour within the vessel by the calculated number of moles, the molecular weight is provided.

His most valuable contribution in this field was the precise determination of the atomic weight of carbon (with his pupil Stas) in 1840. The previously accepted weight, determined by Berzelius as C = 12.20 (O = 16), was shown to be incorrect. Dumas proved that C = 12.000 ± 0.002 (O = 16). Dumas' analysis was made by separately burning diamond, artificial graphite and natural graphite in oxygen; the carbon dioxide formed was weighed in potash solution. All the results were in close agreement and his *new* weight of carbon had a great effect on the progress of organic chemistry.[1,2]

This discovery led Dumas to postulate the existence of a third hydrocarbon analogous to ethylene and isobutylene (2-methylpropene), that had the hydrogen and carbon combined in a 1:1 ratio, although in different states of condensation. He suggested that the three hydrocarbons would constitute a series such that the condensation for each successive term was twice that of its immediate predecessor. In other words, working with the then accepted C=6, ethylene was C_2H_2 and isobutylene C_4H_4 with the new member CH, the immediate predecessor of ethylene. By this reasoning, based purely upon analogy, Dumas predicted and succeeded in discovering the whole methyl series. The first member of the series (CH) was called *methyl*. In this way Dumas not only established a link between ethanol and methanol but also discovered the radical of cetyl alcohol, which had been known from Chevreul's earlier investigations.[1,2]

In 1839 Dumas discovered that the action of chlorine on acetic acid gave a new compound (trichloroacetic acid, CCl_3CO_2H) in which the hydrogen atoms of the acetic acid had been replaced by chlorine. His new compound had virtually the same physical and chemical characteristics as acetic acid, even though the electronegative chlorines had been replaced by strongly electropositive hydrogens. This led to the now accepted formula of the compound. In 1840 Dumas accepted editorship of *Annales de chimie et de physique*.

Despite all these contributions, it was the analysis of the total nitrogen in an organic matrix and the vapour density determination carried out by Dumas that led to his name being immortalised. His method (see also Kjeldahl later) involves the total combustion of the nitrogen-containing material. A sample of known mass is combusted in a high temperature chamber (ca. 900 °C) in the presence of oxygen. This leads to the release of CO_2, H_2O and N_2. The gas-

es produced are then reduced by copper and dried, while the CO_2 is trapped. The nitrogen is then quantified using a universal detector. The method, developed in 1831, is older than the Kjeldahl method, but more convenient in many aspects such as speed, safety, cleanliness, and productivity and cost per analysis. Thus:

Combustion:

$$\text{Sample} + O_2 \rightarrow CO_2 + H_2O + N_xO_y + O_2 + \text{other oxides}$$

Reduction and Separation:

$$CO_2 + H_2O + N_xO_y \xrightarrow{Cu} CO_2 + H_2O + N_2 \rightarrow N_2$$

The problem in the past was that it was not easy to reproduce the conditions required by the Dumas method and for this reason the Kjeldahl technique took the lead and became the classical method for nitrogen/protein determination. Nowadays, thanks to the advances in technology, the Dumas nitrogen determination is becoming more widespread. Results obtained with the Dumas nitrogen determination are usually a little bit higher than with Kjeldahl, since even heterocyclics and nitrogen compounds, e.g. nitrites and nitrates, are detected. In the Kjeldahl method, such compounds are converted into the ammonium ion incompletely or not at all. Recently, an automated instrumental technique has been developed which is capable of rapidly measuring the protein concentration of food samples. The nitrogen content is now measured by passing the remaining gases through a column that has a thermal conductivity detector at the end. The column helps separate the nitrogen from any residual CO_2 and H_2O that may have remained in the gas stream. The instrument is calibrated by analysing a material that is pure and has a known nitrogen content, such as EDTA with 9.59% N. Thus, the signal from the thermal conductivity detector can be converted into a nitrogen content. As with the Kjeldahl method it is necessary to convert the concentration of nitrogen in a sample to the protein content using suitable conversion factors, which depend on the precise amino acid sequence of the protein. The Dumas method is considerably faster than the Kjeldahl procedure and is beginning to compete as the standard method of analysis for proteins for some foodstuffs due to its speed.

J.B.A. Dumas

Of some note is the fact that Louis Pasteur attended Dumas' lectures at the Sorbonne in 1843 while studying at École Normale Supérieure. Pasteur had written to Dumas expressing his zeal for research and met him 1842, subsequently to become his teaching assistant where he began his professional chemistry career; it was Dumas who welcomed Pasteur to the Academy of Sciences at the end of 1862.[4]

Dumas was a moderate conservative but became actively involved in politics after the February Revolution of 1848 that led to the French Second Republic. He was elected to the legislative assembly from Valenciennes, a town in the north of France close to the border with Belgium. This was after the fall of Louis Philippe in February that year. When Napoleon III became emperor in December 1848, Dumas was made a senator and member of the National Legislative Assembly; he became minister of agriculture from 1850 to 1851. He was also a member, Vice-President (1855), and President (1859) of the Paris Municipal Council. Dumas was involved in the transformation and modernisation of the capital, supervising the installation of modern drainage systems, water supply, and electrical systems.[3]

In 1832 Dumas became a member of the French Academy of Sciences and from 1868 until his death in 1884 was its permanent secretary for the Department of Physical Sciences. In 1838, Dumas was elected a foreign member of the Royal Swedish Academy of Sciences. Dumas' health deteriorated over his last two years and in 1884 he spent the winter months in Cannes where he died on April 10 of that year. He is buried at the Montparnasse Cemetery in Paris, in a large tomb near the back wall. His is one of the 72 names inscribed on the Eiffel Tower.

The J.B.A. Dumas grave at Montparnasse Cemetery, Paris

Finally, one of Dumas' quotations:[5]

In chemistry, our theories are crutches; to show that they are valid, they must be used to walk ..... A theory established with the help of twenty facts must explain thirty, and lead to the discovery of ten more.

Jean-Baptiste-André Dumas
Leçons sur la Philosophie Chimique **1837**, *60*
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Johan Gustav Christoffer Thorsager Kjeldahl (1849-1900)

Johan Kjeldahl was born on August 16, 1849 in Jægerpris, a small village in the northern part of the island of Zealand in eastern Denmark.[1] He was the son of Jørgen Pedersen, a local medical officer, and his wife Johanne Georgine (née Lohmann) He was educated at the Roskilde Gymnasium, one of the oldest Danish cathedral schools that dates from the 11th century, and matriculated in 1867. He then entered Den Polytekniske Læreanstalt (Polytechnic College – now Technical University of Denmark) in Copenhagen gaining his MSc in natural sciences in 1873. That year he was employed as an assistant in the Royal Veterinary and Agricultural College, where he gained experience in the chemical laboratory in qualitative and quantitative organic and inorganic analysis. It was the precision and exactness of chemical analysis that impressed him there, and to which the Director, C.J. Barfoed though he was well suited.[1] Then, in 1876, he joined the laboratory set up by the Danish brewer J.C. Jacobsen (and friend of Barfoed) in Copenhagen the previous year. His appointment was to input scientific methods to the operation.

Jacob Christian (JC) Jacobsen was the only child of Christen Jacobsen a long-standing brewer who had run his own brewery prior to his death in 1835.[2] The 24-year old JC then took full responsibility for the brewery. In 1847, in order to cope with increasing demand following the introduction of his traditional Bavarian lager to the Danish masses, JC introduced the name *Carlsberg* as a combination of the name of his sole-surviving son *Carl* and the German word *berg* (hilltop – after the hilltop the brewery was situated on). The first brew was made on November 10, 1847 and sold under the name *Carlsberg Lager Beer*. JC had recognised from his early years the importance of science and he always experimented with processes in an effort to control the various phases of beer brewing. In fact, in 1871, JC set up a small laboratory for his continuing experiments but soon came to the conclusion that serious research had to be run independently by qualified scientists. And so it was that in 1875, the Carlsberg Laboratory was established in Valby (a suburb in the south-west of Copenhagen) to study malting, brewing and fermenting processes. Within the year, Kjeldahl was taken on and he directed the chemical department from 1876 until his fatal heart attack in 1900.[1] Initially, the work of the laboratory took on studies of the chemical, biochemical, physiological and genetic characteristics of the various grain species and yeasts used by the brewery and how these reacted during the brewing process. What is particularly noteworthy is that JC set up the Carlsberg Foundation to run the Carlsberg Laboratory, insisting on having any findings made freely available to the whole brewing industry. By 1878 the Foundation had taken on the humanities as well as the sciences.

The old building of the Carlsberg Laboratory in Valby, Copenhagen (taken by Stork in 2005)

To finance its works the Foundation received a portion of shares in the Carlsberg Brewery. JC's wish was that the Foundation have firm obligations to the natural sciences and take direct responsibility for the running of a corporate enterprise. In 1882, after the death of JC Jacobsen, the Foundation inherited the remaining shares in the Carlsberg Brewery as his will stated that it shall always own at least 51% of the brewery. In May 2007 the Danish Foundation Oversight Authority approved rules that meant the Foundation should own at least 25% of the capital assets of the brewery and 51% of the voting shares. In fact, as of May 2007 the Foundation owned 51.3% of the capital and 81.9% voting capacity in Carlsberg.

Soon after his appointment, Kjeldahl became interested in the transformation of carbohydrates during fermentation. The impact of temperature and the influences of other chemicals on the process were unknown at that time, but it was Kjeldahl who, through a series of systematic and precise investigations, determined some of the factors involved in enzyme action. However, his interests moved to the proteins and their chemical changes during germination, and on alcohol fermentation of beer wort. It was his work here in 1883 that subsequently led to the Kjeldahl nitrogen method that utilised his analytical training to the full. To aid his studies into the protein content of various grains used for brewing (less protein meant more beer), he needed to measure the nitrogen

content present, but existing techniques were unreliable. There was no method available to him that allowed for an accurate and reliable estimation of the nitrogen in the organic components. A procedure developed by Hans Will and Franz Varrentrap in 1841 had samples exposed to red heat with the evolved gases collected in sulfuric acid, but this was too complex for the multiple analyses needed by Kjeldahl. Moreover, the method developed in England by Wanklyn and used by others, which involved permagate oxidation in alkaline solution did not always transform all the nirogen into ammonia. Kjeldahl carried out experiments in acid rather than alkaline solution and showed that ammonia was more easily formed using sulfuric acid. As a result of numerous experiments involving acid concentration he concluded that heating with concentrated sulfuric acid to a temperature a little below boiling followed by the addition of permanganate to the hot solution gave the most accurate and reliable results. His method was faster and more accurate than any other available at the time, used simple equipment, and could be performed by an inexperienced technician. At its most basic, his method involved digesting the organic compound with sulfuric acid, distilling the ammonia produced and back titrating the solution with caustic soda. It was presented by him to the Danish Chemical Society on March 7, 1883 and published later that year.[3]

Johan Kjeldahl in the Carlsberg Laboratory in the 1880s (courtesy of the Carlsberg Archive)

The Kjeldahl method evolved to heating the substance whose nitrogen content is required with sulfuric acid to which had been added potassium sulfate to raise the boiling point (from 337 to 373 °C). Oxidation of the organic substance liberates nitrogen as ammonium sulfate and the reaction is complete when the initially very dark-coloured medium turns clear and colourless. The solution is then distilled with a small quantity of sodium hydroxide to transform the ammonium salt to ammonia. The ammonia is trapped by dipping the end of the condenser into a solution of boric acid to generate the ammonium borate. Back titration of the residual acid with sodium carbonate using methyl orange as indicator leads to the nitrogen content. Thus:

Degradation:

$$\text{Sample} + H_2SO_4 \rightarrow (NH_4)_2SO_4 + CO_2 + SO_2 + H_2O$$

NH_3 Liberation:

$$(NH_4)_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O + 2NH_3$$

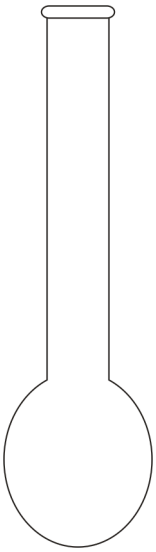
NH_3 Capture:

$$B(OH)_3 + H_2O + NH_3 \rightarrow NH_4^+ + B(OH)_4^-$$

Back-titration:

$$B(OH)_3 + H_2O + Na_2CO_3 \rightarrow NaHCO_3 + NaB(OH)_4 + CO_2 + H_2O$$

In establishing the method, Kjeldahl also developed the distillation flask named after him. The Kjeldahl flask is round bottomed with a long neck that retains the liquid during the digestion/distillation process.



A Kjeldahl flask (E. Generalic, http://glossary.periodni.com/glossary.php?en=Kjeldahl+flask)

In practice, the analysis now is largely automated and available for micro-scale work. Following Kjeldahl's reported method,[3] the catalyst of choice for the decomposition was mercuric oxide but health concerns had it replaced by the less effective copper(III) sulfate that was subsequently supplemented with titanium dioxide. This is the currently the approved catalyst in all of the methods of analysis for protein in the Official Methods and Recommended Practices of AOAC International (the 1884 Association of Official Agricultural Chemists, which changed to the Association of Official Analytical Chemists, then in 1991 AOAC International).

Since 1883, the Kjeldahl method has been refined and tested for a wide variety of substances and is still the standard method used worldwide today for calculating the protein content of substances ranging from foodstuffs to fertiliser and fossil fuels and is now applied to waste water and soils among other samples. While the Dumas method may be faster and now more efficient that that developed by Keldahl, neither it nor any other method can handle the same variety of sizes or conditions of sample. The precision and reproducibility of the Kjeldahl method have made it internationally recognised for estimating the protein content in foods and it is the standard against which all other methods are judged.

Johan Kjeldahl was elected to the Royal Danish Academy of Sciences in 1890 and awarded an Hon. PhD by the Uni-

versity of Copenhagen in 1894. He remained a bachelor throughout his life and had delicate health that manifested itself more during the 1890s. He died from a heart attack on July 18, 1900 at the age of 50 in the seaside village of Tisvildeleje, some 60 km north of Copenhagen. Kjeldahl equipment is used extensively worldwide.

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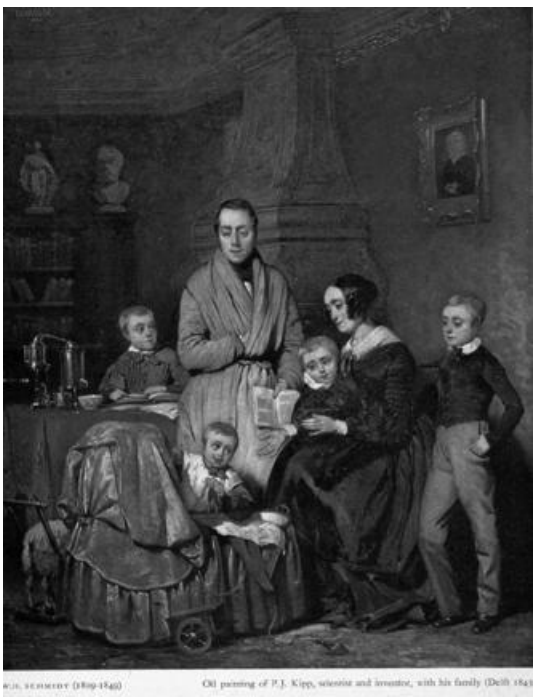
Petrus Jacobus Kipp (1808–1864)

Petrus Jacobus Kipp was born on March 5, 1808 in the city of Utrecht in Holland to Antonie and Adriana (nèe Haastertn). After his schooling he studied at the University there and gained a diploma in pharmacy[1] on October 22, 1829 with a thesis on seven substances.[2] As it so happens his original thesis was rediscovered among the records of an old pharmacy in Utrecht and was purchased by the city of Delft in 2004.[2] It was entitled: *Verhandeling over de navolgende praeparaten; Tartras potassae stibiatum, acidum succinicum, oleum succini, narcoticum, morphium, acetas morphi, acidum meconicum*.[1] Following his examination, Kipp found that contrary to the academic medicine education with national value, his own diploma was valid only locally and, as he wanted to start a pharmacy in Delft, he had to pass a further test by the provincial medical council which he did. About a month prior to gaining his diploma, Kipp married Anna Petronella Regina Heijligers on September 16 (in Utrecht), the daughter of Johannes Philippus and Johanna Adriana den Berger. The couple subsequently had six sons and three daughters of whom one of each died in early childhood. Six of the children had long lives while their third child, Adrianus Pterus (b. 1838) has no recorded death date that this author has been able to trace.

Gaining his diploma to practice in Delft, the 22-year old Kipp bought an existing pharmacy and opened it on August 1, 1830. It was close to the old church[2] and old canal, No. 29 (but now 160) Oude Delft. Some 23 years later he moved to No. 6 (now 204),[1,3] which remained the pharmacy and traded under the name W.A. Kipp (see below) until 2008 prior to moving in the city. The late 1820s saw Delft with a good number of pharmacies and in order to establish himself and provide a living, Kipp, an astute businessman, began trading in chemicals and equipment under the name *Kipp*. Initially it was the chemicals business that made most profit. However, after publishing the first catalogue in Dutch and French that carried descriptions of more than 734 physical, chemical and medical instruments imported from Germany and France in 1850, his sales grew in importance.[1] Alongside these activities, Kipp used his knowledge of geology to analyse minerals. In 1840, he was elected to the medical council of Delft and performed various investigations for the authorities, e.g. of drinking water and of lamp oil used in street lighting. Many pharmacists in those times were working to professionalise their calling and this led Kipp to become one of the 1842 founders of the Netherlands (Dutch) Company for the Advancement of Pharmacy. In January of that year King Willem II founded a Royal Academy in Delft, with the main purpose of training civil servants for the Dutch East Indies. The school rapidly expanded becoming first a Polytechnic School in 1864, an Institute of Technology with full university rights in 1905 (Technische Hogeschool), and finally changing its name to Delft University of Technology in 1986. In the inaugural year Kipp was offered a chair in geology but he declined it for reasons unknown though likely to involve his business interests. However, he profited from sales to the new institution and he supplemented his income by translating German chemistry texts by Cari Noback, Friedrich Wöhler, Carl Steinberg, and Karl Friedrich Plattner into Dutch for use there.[1] Kipp became friendly with many of the college academics and Willem Hendrik Schmidt (1809-1849) painted a lasting family portrait in oil in 1843.[1]

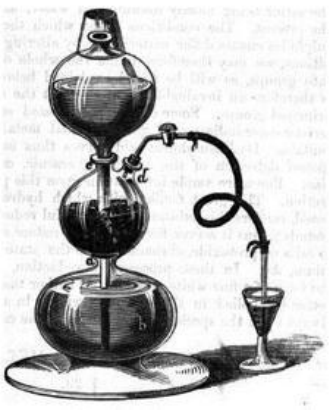


W.H. Schmidt oil painting of P.J. Kipp with his family (Delft 1843) (courtesy of Kipp & Zonen and former employee Leo van Wely who kindly provided much information)

The year of 1842 saw Kipp publish results of research into the presence of arsenic in the livers and kidneys of

rabbits. To obtain the results he used an apparatus to generate hydrogen that had been developed in 1836 by the English scientist James Marsh. In using this apparatus, hydrogen production proved difficult to stop during an experiment and this dissatisfied Kipp for he wanted to generate hydrogen sulfide; he was unable to contain the odoriferous gas. He decided to design his own gas generator and had two models produced in 1844 by the German glassblower Heinrich Geißler. The first was too fragile but the second was much more robust. The two descriptions were separately published that year anonymously in the (obscure) Dutch *Tijdschrift voor Handel and Nijverheid* (Journal for Trade and Industry)[4] of which the second (the *Kipptoestel*) provides the version that we now know as *Kipp's apparatus*.[5,6] Other publications by Kipp refer to these descriptions and they are correctly accredited to him. The oldest known copy of the apparatus is owned by the Boerhaave Museum in Leiden. It is 62 cm high and was made between 1845 and 1875.

The equipment consists of three vertically stacked cylinders, roughly resembling a snowman. The solid material, e.g. iron sulfide, is placed into the middle cylinder, the liquid reagent (usually acid) is put into the top cylinder so that it can pass down a central tube to the bottom container. The middle cylinder has a tube with a stopcock attached and this allows the evolved gas to be drawn off and stopped when appropriate. When the stopcock is closed, the pressure of the gas in the middle cylinder rises and pushes the acid back to the top cylinder until it is not in contact with the solid material anymore, and the chemical reaction stops. The Kipp generator only works correctly when the solid material is insoluble in the acid. It is usually made of glass, sometimes of polyethylene, and remains a commercially available item. Almost everyone will have seen one – the three bulbs stacked on top of each other with an outlet from the middle section – and many of us, no doubt, used one in school or college to generate gases.



Left: Drawing of a Kipp's apparatus from *Elementary instruction in chemical analysis*, by C.R. Fresenius, 1859, p. 33 (Wikimedia). Right: Kipp's apparatus ca. 1900 (courtesy of The Chemical Heritage Foundation)

Whereas many regard 'the Kipp' as a means of generating the notoriously odoriferous H_2S (from FeS/HCl), it has routinely been used to generate H_2 (from Zn/HCl or dil. H_2SO_4), CO_2 (from pieces of $CaCO_3$/HCl), HC≡CH (from CaC_2/H_2O), CH_4 (from Al_4C_3/lukewarm H_2O), Cl_2 (from KMnO4, $Ca(ClO)_2$ or MnO_2/HCl), O_2 [from $Ca(ClO)_2/H_2O_2/HNO_3$ (trace)] and NO (from Cu turnings/dil. HNO_3). In addition, a modified apparatus can be used for reaction between two liquid precursors when a mercury trap is added as a check valve, and the middle bulb is filled with an inert porous material such as pumice, onto which one of the precursors is dropped. In this way hydrogen chloride can be prepared (from HCl/conc. H_2SO_4), H_2S (from a conc .aq. Na_2S/dil. H_2SO_4), SO_2 (from 40% aq. $Na_2S_2O_5$/conc. H_2SO_4), NO (from $FeCl_2$ in HCl/20% aq. $NaNO_3$), and N_2O_3 (from 20% aq. $NaNO_2$/conc. H_2SO_4). The gas produced often requires further purification and/or drying, due to water vapour and/or mist if the reaction is vigorous. The apparatus has found less use since the advent of small laboratory scale gas bottles.

Another source[7] ascribes Kipp as the Dutch chemist who advanced the quinine (kinine) trade. Quinine is the naturally occurring alkaloid that can be extracted from the bark of the Chincona tree and was used by Indians in tropical forests of north-western South America for centuries. Father Calancha, a senior Augustinian monk and pioneering anthropologist who studied the South American natives, wrote in his 1663 book, *Chronicles of Moral Order of Saint Augustine in Peru*, that a decoction of the bark of the "Fever Tree" (weighing the same as two small silver coins) from the Loja region of Ecuador, when drunk, would cure malaria. It became one of the first drugs produced and sold by a global pharmaceutical industry during the nineteenth century and the Cinchona plantations on Java in the Dutch East Indies supplied most of the bark for the quinine pharmaceutical business.

The Second Interbellum article[7] states that: "*On the 4th of May 1847 ….. Petrus Kipp had discovered a new malaria vaccine for the Dutch Army …*". Kipp is said to have analysed the bark brought from Southern Columbia and provided the aqueous solution for use against malaria. In fact, it was French researchers Pierre Joseph Pelletier and Joseph Bienaimé Caventou who isolated and named[8] quinine in 1820 but it had been used to treat malaria in Rome in 1631 as the Jesuit brother Agostino Salumbrino (1561–1642), an apothecary living in Lima, saw the Quechua using the bark of the cinchona tree for that purpose and sent a sample back to Rome. Moreover, the form of quinine most effective in treating malaria was found by Charles Marie de La Condamine in 1737. Nevertheless, the use of quinine by the Dutch Army foreshadowed the cultivation of Cinchona in the Dutch East Indies and Kipp can be credited at least in part for it.

Kipp died suddenly on February 3, 1864 and after this his widow and their son Anthonius Johannes (1834-1916) (an instrument maker) carried on the business under the name Kipp & Zoon for two years until son Wilhelmus Arnoldus (1837-1904) (a pharmacist) joined when it transferred to Kipp & Zonen. After some years the firm bought three premises behind the pharmacy to house its master instrument-maker, Mr. A. Filbry and further developments saw Jan Willem Giltay close his workshop in Dordrecht and move to Delft in 1880 to manage the instrument-making side of the business. When Anthonius Kipp retired in 1887, Giltay became owner of the firm

A 1940 UK Chemistry lab, with (at right) a fume cupboard containing Kipp's Apparatus and one in use on the bench; note also the retort at left (from The Old Almondburians' Society of King James's School, Almondbury, Huddersfield, by Austin Holroyd; with permission)

named P.J. Kipp & Zonen. Wilhelmus Arnoldus continued the separate pharmacy under his own name W.A Kipp. It traded under the same name and at the same place until January 2008 and is now in the centre of the city! Kipp & Zonen B.V. continues as a force in Dutch industry providing class-leading instruments for measuring solar radiation and atmospheric properties in meteorology, climatology, hydrology, industry, renewable energy, agriculture and public health. The chemicals and glassware side of the business transferred to become a third industry, Salm-Kipp, and this now exists as Salm en Kipp B.V. in Breukelen near Utrecht.

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Back to basics – history, philosophy and fundamentals of the patent system

Katherine Hebditch

Baldwins Intellectual Property, PO Box 5999, Wellesley St, Auckland
(email: katherine.hebditch@baldwins.com)

The patent system often draws a lot of debate and controversy, but sometimes this is based on perceptions that are not entirely accurate. In this article we go back to the beginning to talk about where it began, what were the intentions and (briefly) where it is now.

In the beginning

Going all the way back to medieval times the English Crown granted special privileges to trade guilds, corporations and individuals. These were intended to promote new industries, bring skilled craftsmen to England and to ensure high production. However, being granted by the Crown, there was little regulation of the circumstances under which such rights were bestowed. Under Elizabeth I and James I the system was seen to be abused as a means to gather revenue for the Crown with controversial monopolies being granted for common commodities.

In 1628 the English Government stepped in and passed the Statute of Monopolies which set out the law under

which future monopolies would be granted and declared all previous monopolies void. Section 6 of the Statute of Monopolies is seen as the most important. It specified that a patent could be granted to "the true and first inventor" for any "manner of new manufacture" but that there would be a time limit on the monopoly.

These basic principles still hold today. Section 6 of the Statute of Monopolies is still referred to in the present New Zealand Patents Act. However, the procedures and limitations for the grant of a patent have moved on somewhat since these beginnings.[1]

How are these early principles applied today?

The basic principle of the patent system is that a monopoly is granted to an inventor for a limited time in return for making enough information about their new invention publicly available so that others will be able to use it once the monopoly expires.

The information about the invention is contained in a patent specification which is open to public view. This is why a granted patent is called a "Letters Patent"; it is an open letter describing an invention.

The granting of patents in New Zealand is administered by the Intellectual Property Office of New Zealand (IPONZ) and enforced by the courts.

In the Statute of Monopolies the length of a patent was limited to 14 years. Modern New Zealand patents presently have a limit 20 years, but can lapse earlier if renewal fees are not paid to keep it in force.

To be granted a patent in New Zealand today the invention must still be "new" and must also be a "manner of manufacture", as originally stated in the Statute of Monopolies.

The invention being "new" means it cannot have been previously known or publicly disclosed by either the inventor or anyone else prior to the patent application being filed. The law also now specifies that the invention must be "inventive" and "useful". This means it is more than just a simple advance from what is already known and must be able to fulfil a real life function.[2]

What is meant by the slightly strange and archaic wording from the Statute of Monopolies that the invention is a "manner of manufacture", has been analysed and interpreted by many judges over the years. It has the advantage that it is sufficiently general that it can be interpreted with reference to modern inventions that could not have even been conceived of back in 1628. For example, the Australian High Court (Australia also references Section 6 of the Statue of Monopolies in its patent law) recently considered whether an isolated nucleic acid coding for the mutant *BRCA1* gene could be considered a "manner of manufacture".[3]

In addition to the limitation that the invention must be a "manner of manufacture", the New Zealand Patents Act now sets out specifically excluded subject matter including "human beings and biological processes for their generation" and also that the invention must not be "contrary to public order or morality". This wording also allows for consideration of as yet unknown inventions and whether it is morally acceptable to grant a patent for them.[4]

Patents are still granted to the "true and first inventor", but commonly now the inventor will assign the rights to a patent application to the company that is funding the development of the invention. It is a common clause of an employment agreement that any inventions devised as a part of normal employment duties will be assigned to the employer.

Latest developments

While the basic principles remain the same, patent law in New Zealand is still evolving, often by interpretations of the law by judges and sometimes by changes to the law made by Parliament.

If the recent Trans-Pacific Partnership Agreement (TPPA) is ratified by New Zealand, the law will need to be changed to adopt the "grace period" system already used by some other countries. This means although an invention must still be "new", a public disclosure of the invention originating from the inventor up to one year before the patent application is filed will not mean the ability to be granted a patent is lost.

The length of the patent term also appeared to be hotly debated in the TPPA negotiations. Some people believe the term for a patent to a device with a relatively short and inexpensive development time should not be the same as a pharmaceutical that can be in development for years and cost billions of dollars. Some countries, but not New Zealand, allow limited extensions to the patent term for pharmaceuticals. These are often linked to the time it takes to get regulatory approval to sell the drug. It appears there was pressure to adopt this approach in New Zealand, but the final TPPA allows for extensions only where there are unreasonable delays in the examination process (for any type of invention) or unreasonable delays in the regulatory approval process for a pharmaceutical product.

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

katherine.hebditch@baldwins.com Patent Proze, Baldwins Intellectual Property, PO Box 5999, Wellesley Street, Auckland.

References and notes

1. New Zealand Patents Act 2013, Section 14(a).
2. New Zealand Patents Act 2013, Section 14(b) and (c), with a few minor exemptions for disclosers set out in Section 9.
3. High Court of Australia, *D'Arcy* v *Myriad Genetics Inc*, [2015] HCA 35.
4. Exclusions are listed in Section 15 and 16 of the New Zealand Patents Act 2013. Section 11 also states a computer program is not an invention and not a manner of manufacture.

Dates of Note 2016

April

24 Petroleum was discovered on the Egyptian shore of the Red Sea in 1886 and the first IBM personal computer was introduced in 1981.

25 The integrated circuit was patented by ***Robert Noyce*** in 1961.

27 ***Wallace Hume Carothers***, the American chemist who developed nylon, the first synthetic polymer fibre to be spun from a melt in 1935, was born in 1896 and died on April 27 in 1937.

28 In 1926, the term *wave mechanics* was coined by nuclear physicist ***Erwin Schrödinger*** in a letter he sent to Einstein. It is the day in 1986 that Russia announced the Chernobyl nuclear disaster, two days after it happened.

May

1 The 1851 Great Exhibition of the Works of Industry of All Nations opened in Hyde Park, London, England. This was the first international exhibition to be held in any country. Housed in Paxton's magnificent Crystal Palace, it provided a showcase for many thousands of inventions.

5 ***John William Draper***, the English-American chemist who pioneered the study of photochemistry (see: This Journal, **2013**, *77*, 136-141), was born this day in 1811.

This same day in 1881 saw ***Louis Pasteur*** test inoculations against anthrax on an ox, several cows and 25 sheep. His experiment proved successful, and was a milestone in the treatment of disease.

6 ***Victor Grignard***, known for the organomagnesium reaction named after him and co-recipient (with Sabatier) of the 1912 Nobel Prize for Chemistry, was born in 1871.

8 ***Thomas Hancock***, the English inventor, manufacturer and founder of the British rubber industry known for the *masticator* that worked rubber scraps into a shredded mass of rubber able to be formed into blocks or rolled into sheets, was born in 1786.

This same day in 1951 saw synthetic fibre available in men's suits consisting of 55% Dacron and 45% worsted. Dacron, a DuPont trademark, became the first commercially marketed polyester fibre available as yarn, staple, and fibrefill.

10 ***John Desmond Bernal***, the Irish physicist and X-ray crystallographer, was born this day in 1901.

11 ***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 in 1981.

12 ***Anselme Payen***, the French chemist who contributed to industrial chemistry by discovering cellulose, synthesising borax from soda and boric acid and (in 1820) creating a new industry that marketed the synthetic product at one-third the price of the refined natural borax, died this day in 1871. He also found the value of

The interior of the crystal palace

animal charcoal to clarify sugar solutions and then in 1833 discovered the first enzyme, now called *amylase*.

14 ***Bruce Merrifield***, the American biochemist and 1984 Nobel Laureate in Chemistry for his development of the solid phase peptide synthesis method to build large organic molecules on a solid matrix, died this day 10 years ago.

It is the day in 1856 ***Charles Darwin*** began writing his book, *The Origin of Species,* sitting in the study of his country home in Down, England.

15 ***Joseph Loschmidt***, the Austrian chemist and physicist who first proposed a cyclic structure for benzene and many aromatic hydrocarbons in 1861, was born in 1821.

18 ***Vincent du Vigneaud***, the American biochemist and winner of the 1955 Nobel Prize for Chemistry for his work on biochemically important sulfur compounds and for the first synthesis of a polypeptide hormone, was born in 1901.

20 ***Christopher Columbus*** died this day 410 years ago, while in 1921, ***Marie Curie*** was presented with a gram of radium worth $100,000 at the White House, Washington, DC.

21 ***Carl Wilhelm Scheele***, the Swedish chemist who discovered oxygen in 1772, died in 1786.

It is 100 years ago that Daylight Saving Time was introduced in Britain as a war-time measure to save fuel.

24 ***Daniel Gabriel Fahrenheit***, the German physicist best known for inventing the alcohol and mercury thermometers and for the temperature scale named after him, was born this day in 1686.

25 ***Carl Wagner***, the German physical chemist and metallurgist who helped shape the field of chemical metallurgy as an exact science, was born in 1901.

27 ***Conrad Arnold Elvehjem***, the American biochemist who identified nicotinic acid as a vitamin, which when absent from the diet resulted in the disease pellegra (a disease characterised by diarrhoea, dermatitis and dementia), was born in 1901.

28 ***Alfred Otto Carl Nier***, the physicist who refined the mass spectrometric process to distinguish isotopes, was born in 1911.

It is the day in 1991 that *Production of taxol or taxol-like compounds in cell culture* was patented.

29 ***John Walker***, the English chemist who invented the striking match, and ***Henri Braconnot***, the French chemist who first isolated glucose directly from such plant material as sawdust, linen or bark by boiling them with acid, were both born in 1781.

30 ***Joseph Kennedy***, one of the four co-discoverers of plutonium (element 94), was born 100 years ago.

Rosalyn S. Yalow, the American biophysicist who shared (with Schally and Guillemin) the 1977 Nobel Prize for Physiology or Medicine for the development of radioimmunoassays (RIA) of peptide hormones, died 5 years ago.

31 ***Louis J. Ignarro***, the American pharmacologist who (with Furchgott and Murad) was co-recipient of the 1998 Nobel Prize in Physiology or Medicine for the finding that nitric oxide is a signalling molecule in the cardiovascular system, and providing an entirely new mechanism by which blood vessels in the body relax and widen, was born in 1941.

June

2 ***Charles-Bernard Desormes***, the French chemist who collaborated with Nicolas Clement to determine the exact composition of CO and CS_2, was born in 1771.

Nicolas Appert, the French inventor, chef, confectioner and distiller who invented the method of preserving food by enclosing it in hermetically sealed containers, died in 1841.

3 ***Jean Antoine Claude Chaptal***, the French chemist who authored the first book on industrial chemistry and coined the name *nitrogen*, was born in 1756.

William Thomas Astbury, the English physical biochemist and the first to use X-ray diffraction patterns to study the structure of nucleic acids, died in 1961.

5 This day in 1981 was when the epidemic disease, later to be named as *AIDS*, was described by Dr Michael Gottlieb in the newsletter of the US Centers for Disease Control.

7 ***Robert Sanderson Mulliken***, the American 1966 Nobel Prize Laureate known for the interpretation of molecular spectra, the application of quantum theory to the electronic states of molecules, and (with Hund), the molecular-orbital theory of chemical bonding, was born in 1896.

It is also the birth date in 1847 of Sir ***James Young Simpson***, the father of modern anaesthetics who employed ether for the first time in Britain, and chloroform for the first time as an anaesthetic in an operation.

Joseph von Fraunhofer, the German physicist and first to study the dark lines in the solar spectrum (the Fraunhofer lines), died in 1826.

8 ***Francis Crick***, known for establishing the structure of DNA, was born this day 100 years ago.

9 ***Gustav Tammann***, the Russian chemist who helped to found the science of metallurgy, was born in 1861.

10 ***André-Marie Ampère***, the French mathematician and physicist who founded and named the science of electromagnetism and suggested that an anhydrous acid prepared two years earlier was a compound of hydrogen with an unknown element, analogous to chlorine, for which he suggested the name fluorine, and for whom the unit of electricity is named, died in 1836.

11 ***Julius Arthur Nieuwland***, the Belgian-born American organic chemist who studied reactions of acetylene and invented neoprene, died in 1936.

12 ***Lyman C. Craig***, who developed the counter-current distribution method, was born in 1906.